1969

A CONCEPT OF PRE-ENGINEERED, PREFABRICATED, PRESTRESSED MODULAR AND MULTI-MODULAR SEALING SYSTEMS FOR OUR MODERN BRIDGES AND STRUCTURES

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- -

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INTRODUCTION.

Whether a bridge be of suspension, cantilever, steel arch, continuous truss, cable stay, concrete arch, continuous plate, orthotropic, box girder, etc. design, there are marked similarities in performance requirements insofar as a sealing system is concerned. These similarities have indicated the feasability of solving the problems at the joints by a systems approach.

As European engineers are impressed with our mass production techniques and demonstrated ability to produce simple low cost structures at a rapid rate, so a visitor to Europe cannot fail to marvel at the sweeping, continuous, architecturally pleasing freedom of design evidenced by our European counter-parts. As a by-product of this increased latitude in design thinking, new problems have arisen that must be solved at the joints, as well as the bearings, if we are to continue to progress. Single module, modular and multi-modular sealing systems based on the compression principle seem best suited to assist engineers in freeing themselves from the conventional for they offer the greatly increased performance levels so necessary to the new structural sophistication that is now spreading across North America.

This discussion is intended to better acquaint the bridge designer with what is being done today in modular compression sealing systems, their capabilities, some of the problems incurred and certain fundamental construction practice considerations.

HISTORICAL RELIABILITY OF MODULAR SYSTEMS

European modular systems, which have preceded the North American types, have field proven their reliability on literally thousands of bridges, predominately of longer spans, with significant displacements and deformations.

As an example of this wide-spread acceptance, there exists printed reference lists for engineers to scrutinize of well over 500 modular systems on bridges in the little country of Switzerland, alone, installed over the past decade, utilizing the popular RUB System (Referenzlists-Elastische Fugenubergange, System RUB, July 1968).

The writer has personally condition surveyed and photographed hundreds of bridges incorporating modular systems in the past 5 years throughout Europe and has yet to find even one in a state of distress, a remarkable observation when one ponders the encompassing magnitude of the sealing problem. They are not only watertight but many actually appear to be airtight as well.

While there has been some replacement of the modular packages, it has been to either add to or detract increments from the modular device for reason of time dependent, unanticipated, unpredictable, permanent geometric changes in the distance between span ends, unusual subsidence problems, etc.

Watson, Stewart C.

THE NEED TO EXTEND THE MAINTENANCE FREE LIFE OF STRUCTURES.

Rapidly increasing costs not only of new construction but of required maintenance on our bridges and structures is dictating the need for improvements in our jointing systems.

Figure 1 shows typical traffic on Golden Gate Bridge carrying more than 75,000 vehicles per day. It not only is extremely dangerous to work on this as well as other high density bridges, particularly during fog conditions, but to hold up traffic while repairing joints actually can produce near disaster traffic jams. Truck loads of foreign material including 3" stones are regularly removed from joints by maintenance forces on Golden Gate Bridge.

The joints on George Washington Bridge were recently reconstructed utilizing compression seals, (See Figure 2). Traffic requirements mandated that work had to be done in the middle of the night only, one lane at a time on a contractual basis with penalty clauses for inability to meet a 30 day completion date.

Figure 3 illustrates the newly constructed Delaware Memorial Bridge. The original structure built 15 years ago approximated 35 million dollars while the new twin bridge, predominately similar in design, cost in the area of 76 million dollars reflecting the higher costs of today and increasing value of our bridges.

Figures 4-A, 4-B, & 4-C portray the Tagus bridge, its main tooth gear bearings taking a total of 112 inches of movement. The expansion joints were built in modular units splitting the movement and dilatations into tolerable widths. After considerable field modification, these joints are now performing mechanically in a superb manner. However, regular vacuum cleaning maintenance is a necessity.

Figure 5A shows the beautiful new Firth of Tay Bridge at Dundee, Scotland and the accompanying photographs (Figures 5-B & 5-C) show typical distress at the expansion joints and intermediate joints.

Figures 6-A, 6-B, & 6-C display the new aerodynamic design of deck on majestic Severn Bridge, part of the M4 Motorway between England and Wales. While the jointing system employed performs with structural adequacy, its design permits the entry of free water, incompressables up to 3/4 inch diameter, requires a major steam cleaning once every month and must be greased regularly for proper operation.

Figures 7-A, 7-B, & 7-C depict the New Forth Road Bridge in Scotland and the jointing systems employed. All of the seals in the intermediate joints have failed and since an expansion jointing system similar to that of Severn Bridge was employed, similar maintenance problems and costs are occurring.

Figure 1. Typical traffic on bridges makes maintenance costly and dangerous (Golden Gate Bridge).

Figure 2. Compression seals had to be installed during night, one lane at a time, under exacting time schedule on George Washington Bridge.

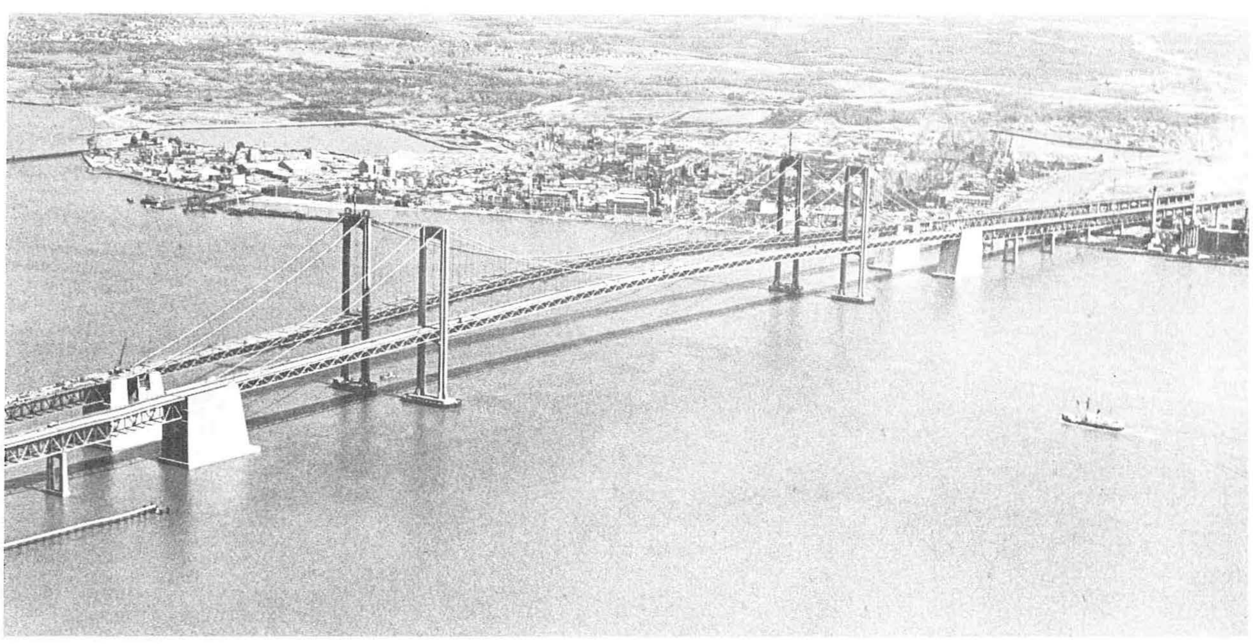


Figure 3. Cost of original Delaware Memorial Bridge-$35,000,000. Cost of new twin Delaware Memorial Bridge-$76,000,000. Original structure is now being compression sealed.

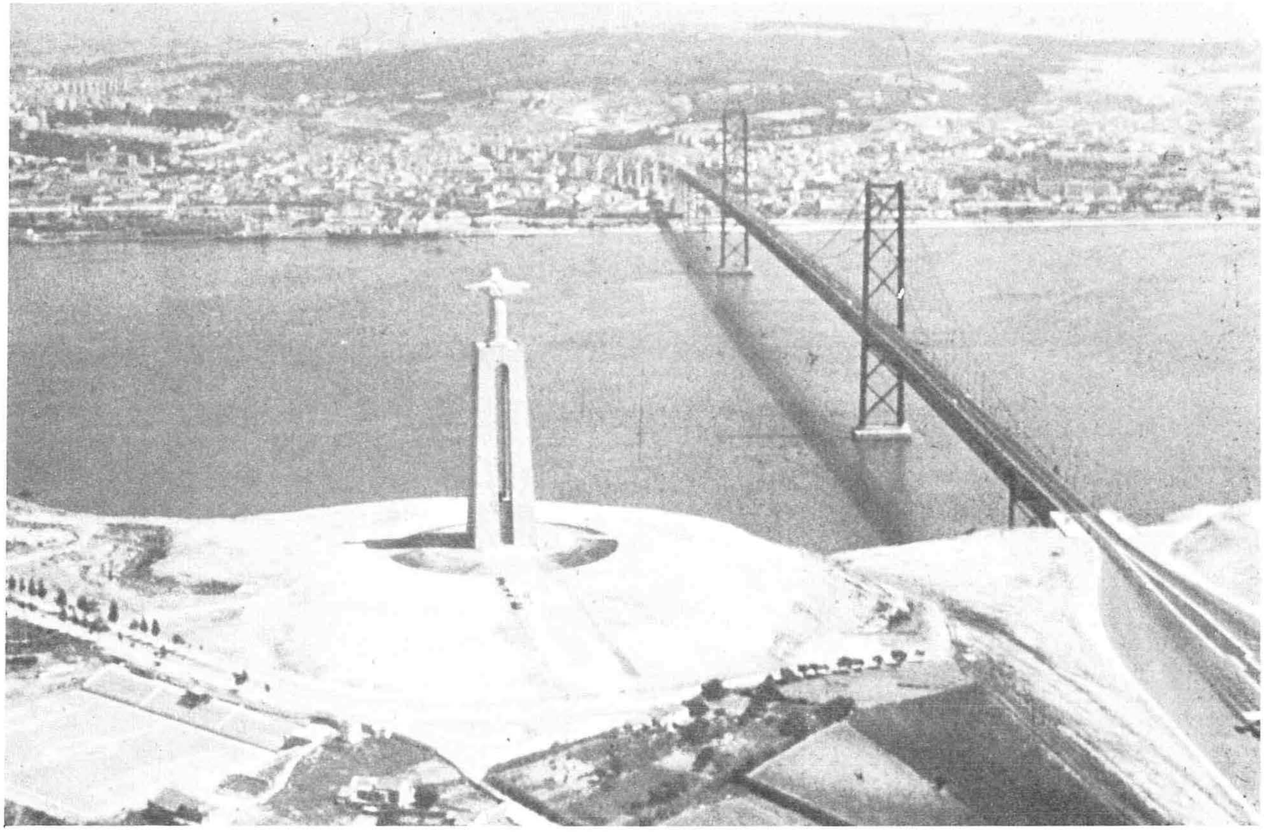


Figure 4-A. Tagus Bridge at Lisbon, Portugal (Pont d' Salazar).

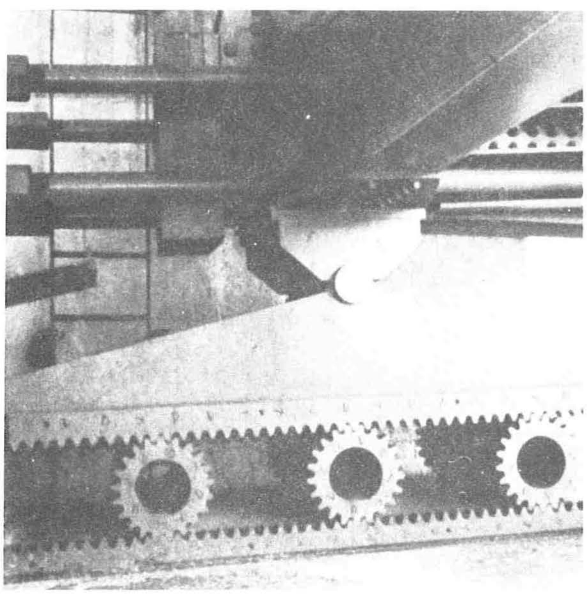


Figure 4-B. Massive gear bearings take large movements on Tagus Bridge.

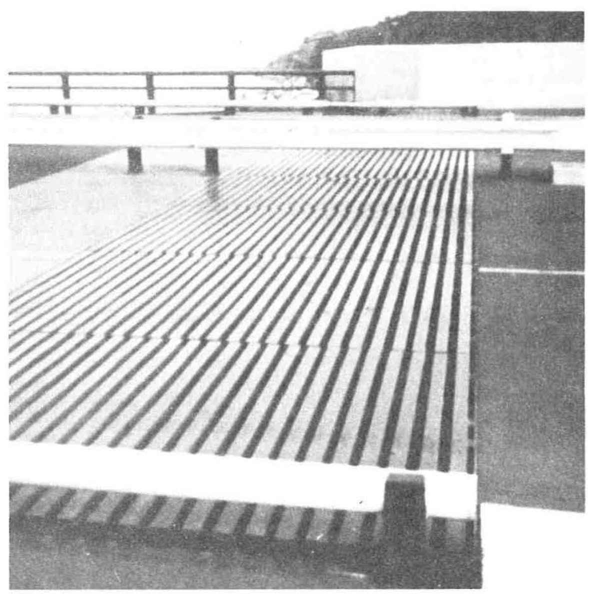


Figure 4-C. 112-inch movement problem minimized by modular concept. (Tagus Bridge).

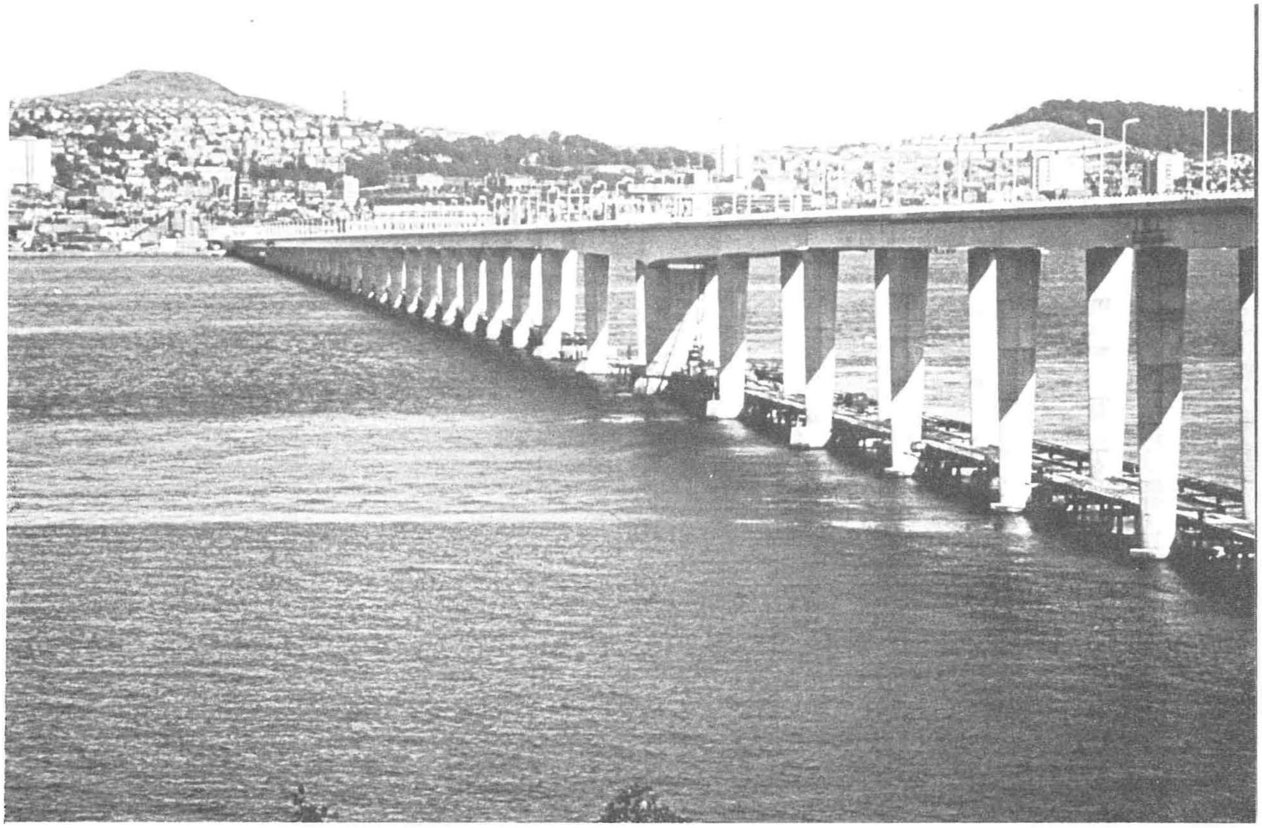


Figure 5-A. Firth of Tay Bridge at Dundee, Scotland. 42 spans totalling 7365 ft. in length.

Figure 5-B. Tay Bridge-Typical distress at intermediate joints.

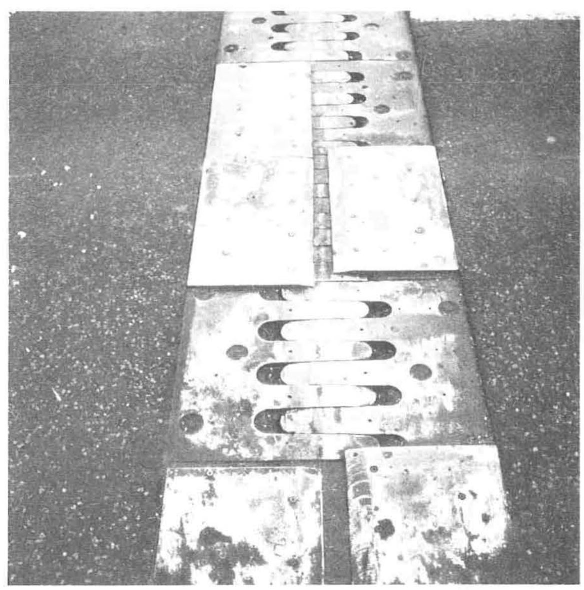


Figure 5-C. Tay Bridge-Typical distress at finger joints. Opened to traffic in August 1966.

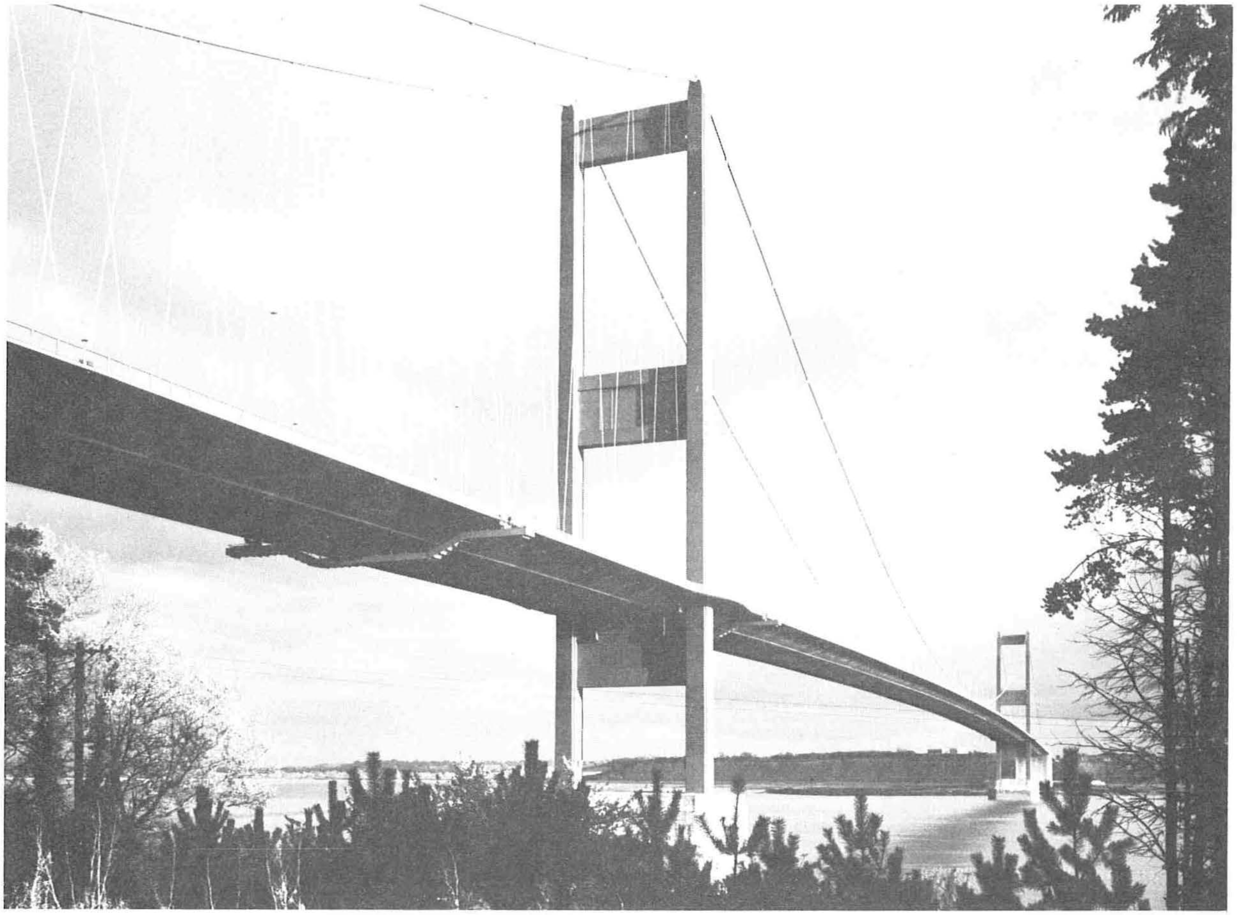


Figure 6-A. Severn Bridge on M4 Motorway between England and Wales (Freeman Fox & Partners).

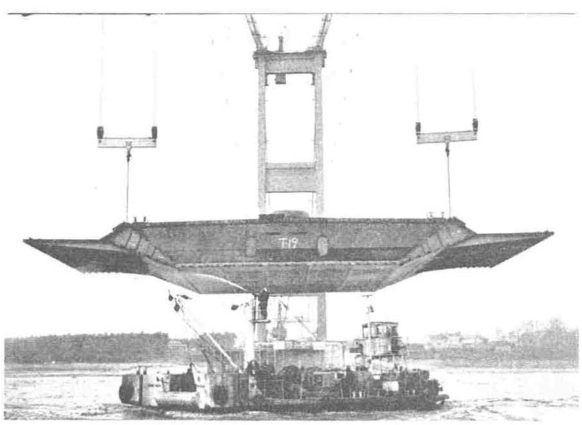


Figure 6-B. Severn Bridge employed new aerodynamic stability with shallow box configuration instead of stiffening truss.

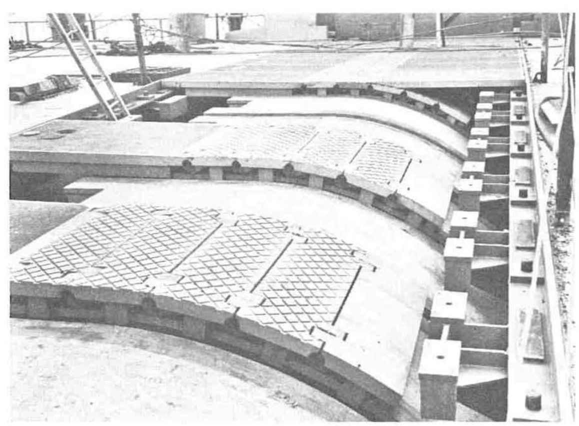


Figure 6-C. Rolling chain joint requires constant maintenance, removal of foreign material, monthly steam cleaning, greasing of parts, maintaining oil levels to prevent chatter on Severn Bridge.

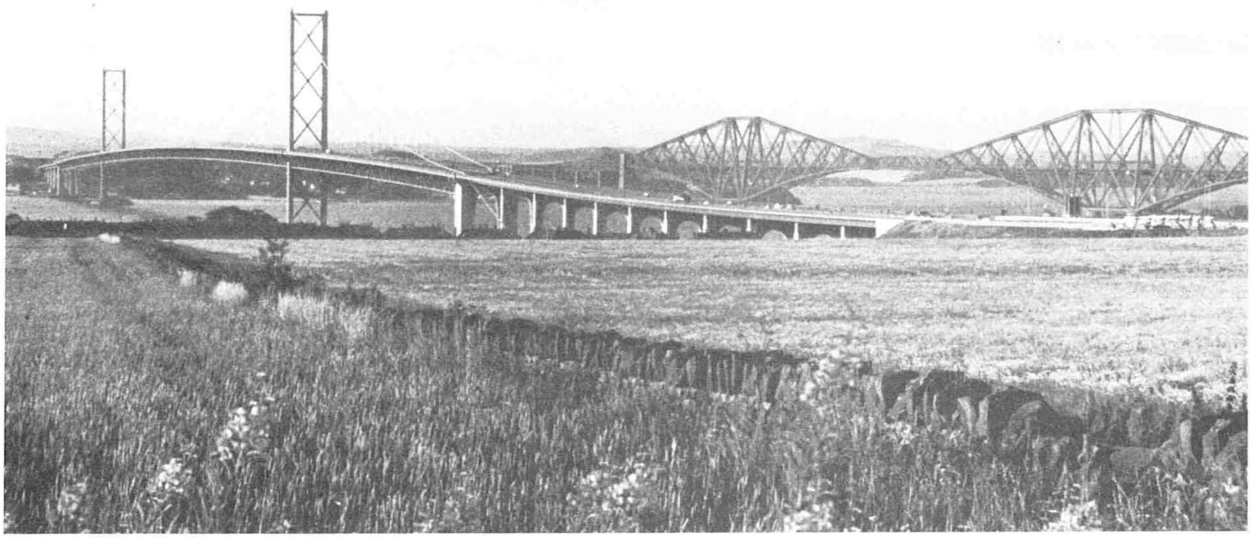


Figure 7-A. Forth Road Bridge near Edinburgh, Scotland (Forth Rail Bridge in background).

Figure 7-B. Forth Road Bridge - Joints of rolling leaf type take center span movement of 68 inches, side span movement of 17 inches.

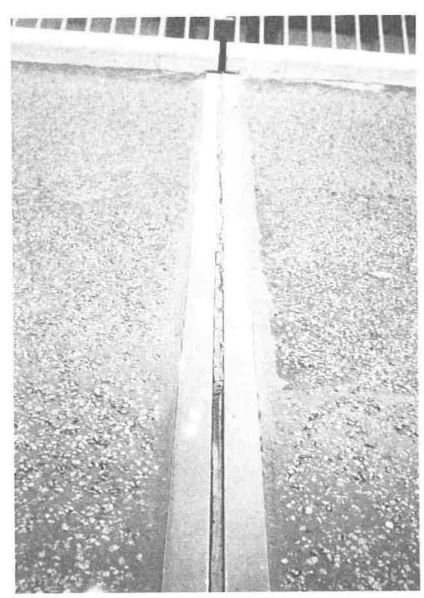


Figure 7-C. Intermediate joints on Forth Road Bridge show typical pattern of distress when movement capability of a stress reversing sealant is exceeded.

Bridges have changed the economy of the world because they vitally affect the accessibility of land. It is therefore incumbent upon bridge designers to exercise every possible means at their disposal in the light of present knowledge to utilize maintenance free concepts in the design of modern bridges and structures.

WEIGHT AT THE JOINTS IS A NECESSITY.

Despite the heavy continuous loading to which the technically highly developed bridge superstructures are subject, economy and weight reduction are primary considerations in present day designs. These considerations do not, however, apply to the design of deck expansion joints. Insofar as slender and light bridges are concerned, heavy, strong deck expansion joints appear to be much less subject to trouble and maintenance.

Furthermore, if chosen from the outset, the total cost of a heavy duty construction is lower than that of a light design, which usually will require much maintenance, repair and makeshift replacements, thus ultimately giving way to a heavy construction after all. Figures 8, 9-A & 9-B illustrate this clearly.

Concrete pavement designers have long felt that the joint is the weakest part of the pavement. So it is with bridge design; the joint area is the weakest and most vulnerable area and the question is now being asked after viewing considerable wholesale distress at bridge joints, should not the joint be stronger than rest of the deck?

IMPROVED IMBEDMENT PRACTICE FOR ARMOR PLATING OF JOINTS

Some of the possible variables in concrete construction practice, unfortunately ever present, have given rise to concern on the part of bridge design engineers throughout the world regarding the ability of the average workman to produce good consolidation of concrete under the flat surfaces of imbedded angle irons, channels, etc. which, as an integral part of a sealing system, can be pounded loose under repetitive traffic loading. Studies now exist which show the merit of very heavy steel cross sections to provide damping to truck traffic induced, damaging vibrations. It is the design practice in a few countries to fasten armored joints to the main reinforcement of the structure in such a solid manner as to take no credit for lug imbedment, treating them as a cantilever. Condition surveys of bridges in service in United States as well as other countries suggests that this is an area for needed research.

Figures 10-A & 10-B show examples of an armoring method now coming into usage in Switzerland giving evidence of concern for this problem. A fine steel mesh is shot-welded to all imbedded surfaces preventing the large aggregates from coming in direct contact with the galvanized armor. After placement, an epon grout mix is injected through vent holes to guarantee positive consolidation. Since there are a fair number of experienced American bridge engineers who feel it is probably not possible for the long term to keep armored interfaces from eventually rocking in high traffic

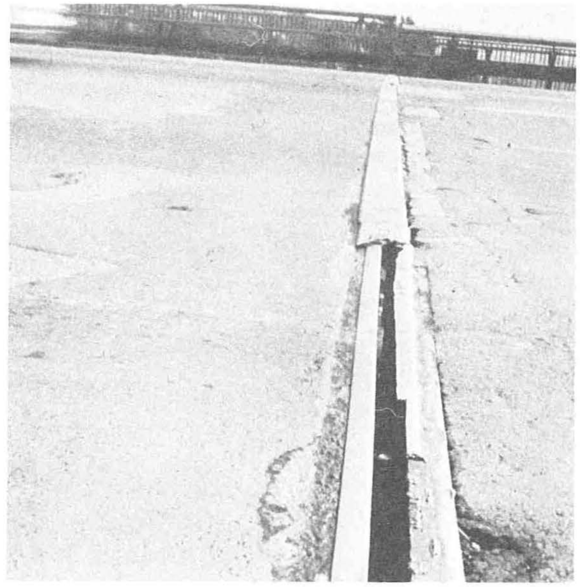


Figure 8. End result of structurally inadequate armor.

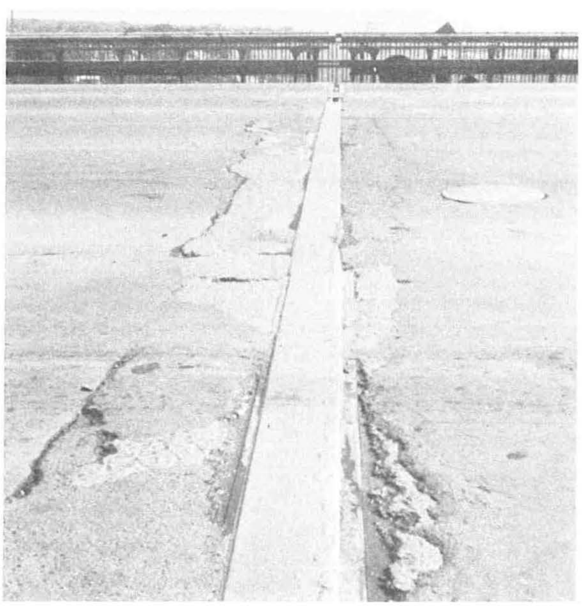


Figure 9-A. Typical distress due to inadequate damping, lightweight steel (North America).

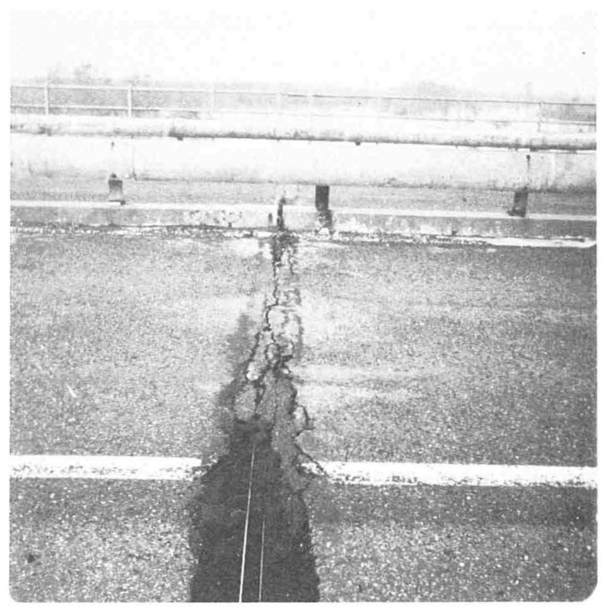


Figure 9-B. Typical distress due to inadequate damping, lightweight steel (Italian Autostrada)

density areas, it might be well to experiment with design thinking similar to Figure 10. There can be no question about the future necessity to permanently fasten a sealing system to the bridge and since the joint opening is subject to constant dynamic loads, its design must always be superior to that of the rest of the riding surface.

UPWARD VERTICAL FORCES

Experience over the better part of a decade with monolithic bridge compression seals together with a massive dynamic compression seal failure on a large 3 mile long bridge structure during the early part of 1968, has settled once and for all time the question of the necessity for some mechanism to provide for resistance to vertical forces, both upwards as well as downwards. The writer has personally observed a good part of 20,000 lineal feet of one configuration of bridge seal migrating in an upward direction on a warm spring day under a condition of heavy showers. It is the apparent effect of the presence of large amounts of free water coupled with almost instantaneous opening and closing of joint interfaces, from rotation under live loading, to produce a super-lubricated condition at the joint walls. While there were other mitigating forces, there can be no question that these seals actually were forced upwards and out of the joints creating an extremely hazardous condition to traffic.

Under a state of super-lubricity during heavy rains, it appears logical that a suction force is applied by rubber tires not unlike that from a rubber sink plunger.

Certain types of seal configurations which produce more stress at the top rather than at the bottom also tend to walk upwards under rotational effects. Only field proven seal configurations should be utilized since all shapes differ in their ability to resist upward vertical forces. Ideally, seal configurations used should incorporate a capability to translate upward and downward vertical forces into a lateral force, with the forces being dissipated against the joint interfaces, (see Figure 11-A).

DOWNWARD VERTICAL FORCES

There can be no question but that downward vertical forces from traffic loadings and to some degree, gravitational, must be given consideration in the design of any sealing solution. Figure 12 shows a 5 year old seal installation on the departure level deck structure of LaGuardia Airport Terminal Building giving evidence of the effect of downward vertical force. The seal at the right side of the picture has migrated downward to the bottom of the slab permitting hard foreign materials to enter the joint en masse potentially creating a condition or overstress at high temperatures. This is the traffic side of the curb where taxis and vehicular traffic are employed. To the left of the curb where there is no traffic, and no downward vertical forces occur, the seal is in excellent condition, apparently unaffected, having been installed in 1963.

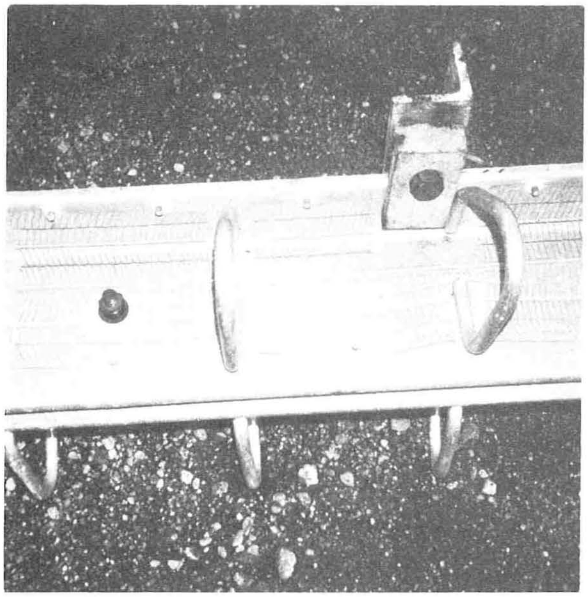


Figure 10-A. Swiss-Italian armored joint utilizes new concept for imbedment, shot welded mesh on under side of angle irons, post-installation grouting.

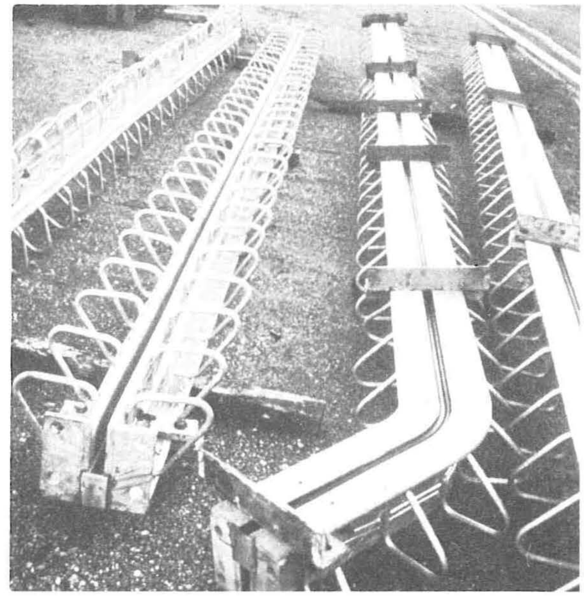


Figure 10-B. Factory prefabricated single module compression seals, prestressed to mid-point of movement, galvanized, shot welded mesh with grout holes, soft radius for skews.

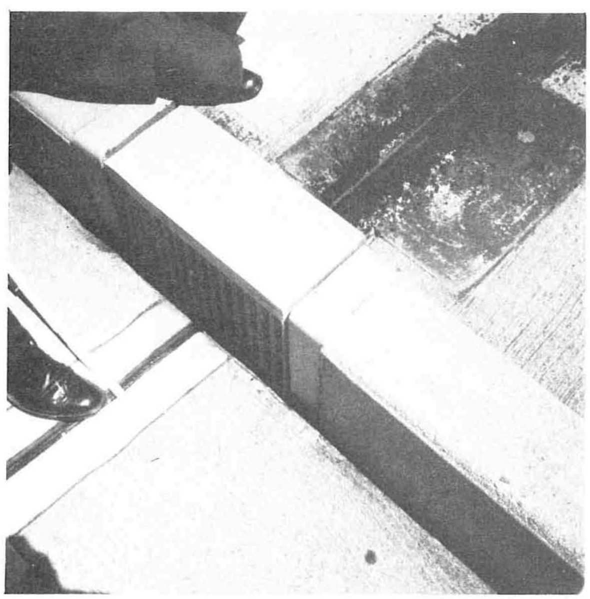


Figure 12. After 5 years of service life, seal migrated downward in traffic area (Upper right). Seal stayed in place to left of curb with no traffic. (La Guardia Airport departure level structure)

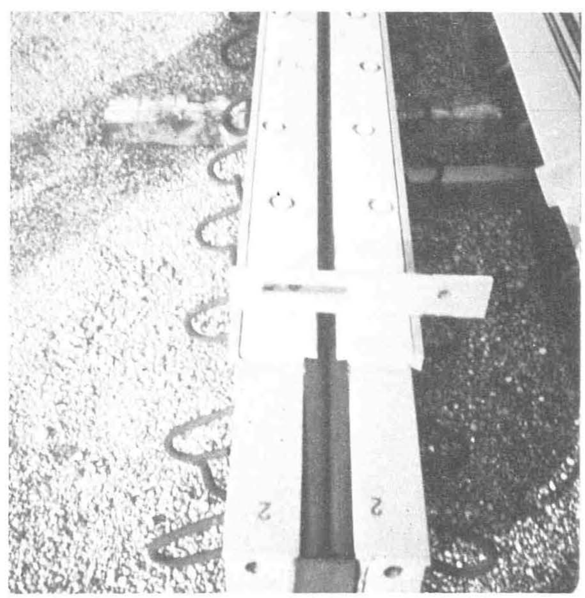


Figure 14. Cantilevered armor reduces joint gap, prevents movement from upward vertical forces. (Swiss-German design)

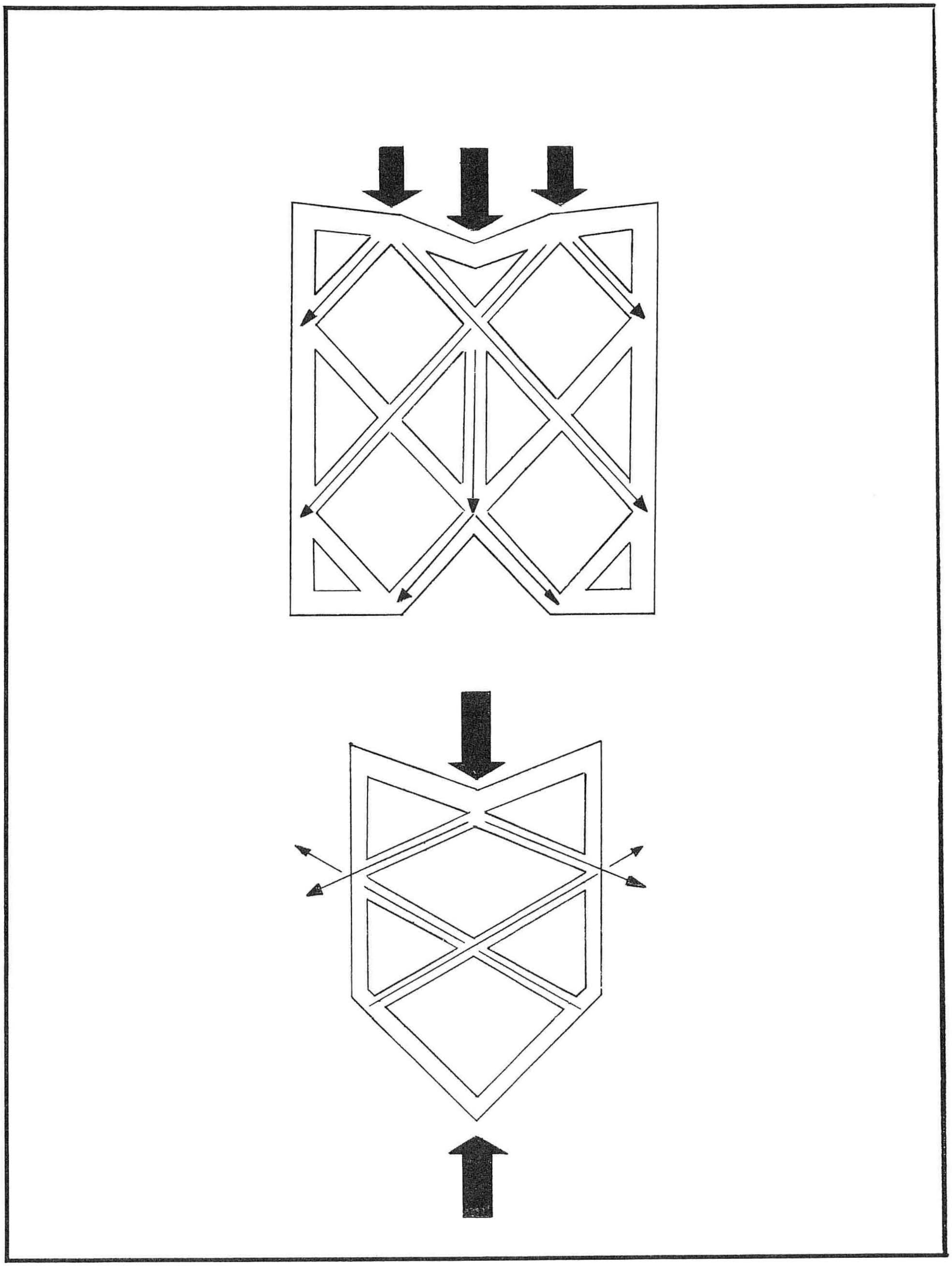


Figure 11-A. Arrows indicate translation of vertical force to lateral force.

Watson, Stewart C.

HEAVY DUTY SEAL CONFIGURATIONS ARE MANDATORY FOR BRIDGES

Certain experimental light webbed seal configurations that have recently come into view and which are being suggested as adequate for bridge joint environments have given cause for concern on the part of design engineers.

The first experimental bridge compression seals were actually hybrid devices consisting of thin webbed contraction joint seal shapes which were bonded together to achieve the greater width and movement stroke as necessary to the needs of bridge joints. (See Figure 11-B).

While they initially appeared to be successful insofar as longitudinal stroke of movement was concerned, it later became strikingly evident that there was an absolute need for heavier webs, heavier tops and heavier sides to structurally resist not only vertical forces but the very serious effect of foreign material being pounded by heavy traffic into the top and at the interfaces of the joints. In the long term, this intrusion tended to depress a light webbed seal configuration into itself in a downward direction. The relatively thin webbed cross sections (Figure 11-B) as compared to the field proven standard North American heavy duty bridge seals now in wide usage (Figure 11-C) tended to take intrusions of foreign material at interfacial locations as the thin tops were unsymmetrically depressed under the effect of traffic loadings.

Obviously, both of these typical service conditions are intensified during colder weather as the joints open to their extreme movement stroke. Frozen snow, ice, slush, maintenance grits, etc., lying on top of the seal are slammed and ground into the configuration, a performance requirement which mandates the very ultimate in brute strength.

The design team responsible for field testing and development of these bridge compression seals after experience on literally thousands of bridges in every conceivable type of environment throughout North America made the considered judgment that webs, sides and top section thicknesses as shown in Figure 11-C represent absolute minimums. Being arrived at through the committee system, they take into account the dictates of bridge performance need,structural considerations, rubber manufacturers' capabilities, surface contact requirements, pressure generation minimums and ease of installation. To thin out webs in an attempt to obtain a greater movement stroke without taking into account the above needs is an abortion of a proven concept.

MINIMUM PRESSURE GENERATION FOR BRIDGE SEALS

Specifications should be written to exclude flimsy, low pressure configurations since they have been proven to have no place in the difficult bridge environment.

The following ranges of pressure generation minimums appear to be adequate for bridge seals:

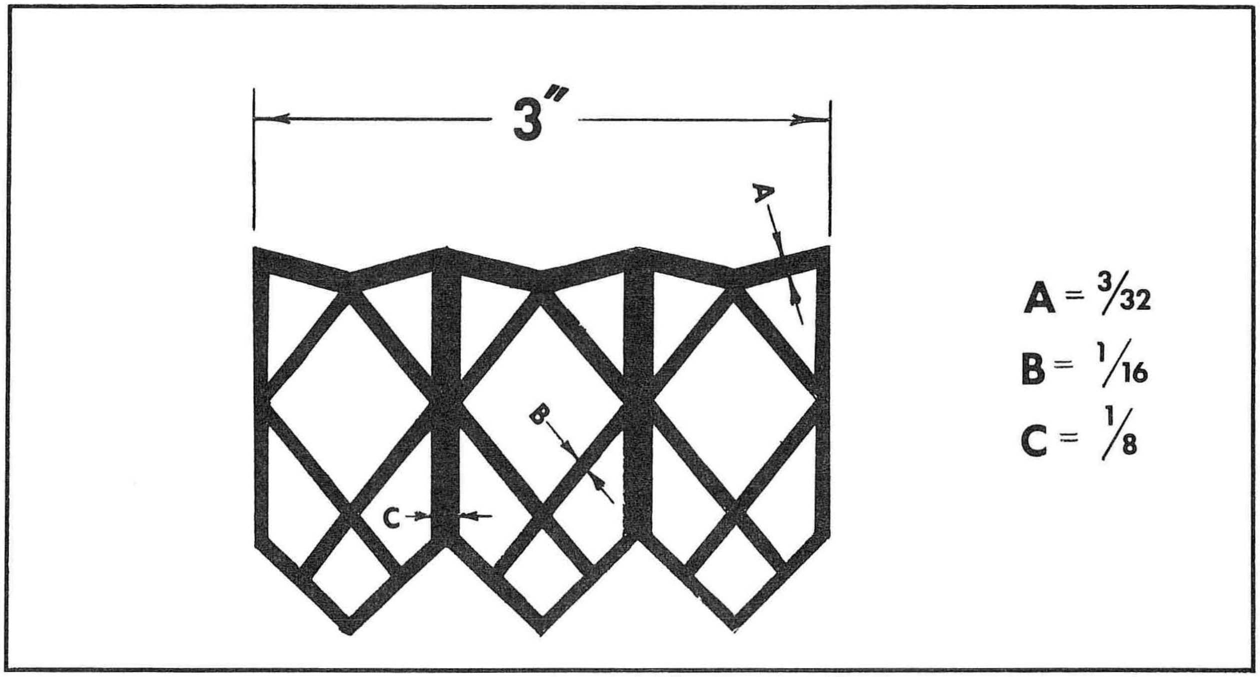


Figure 11-B. Early light webbed seals proved too flimsy for bridge joint environment.

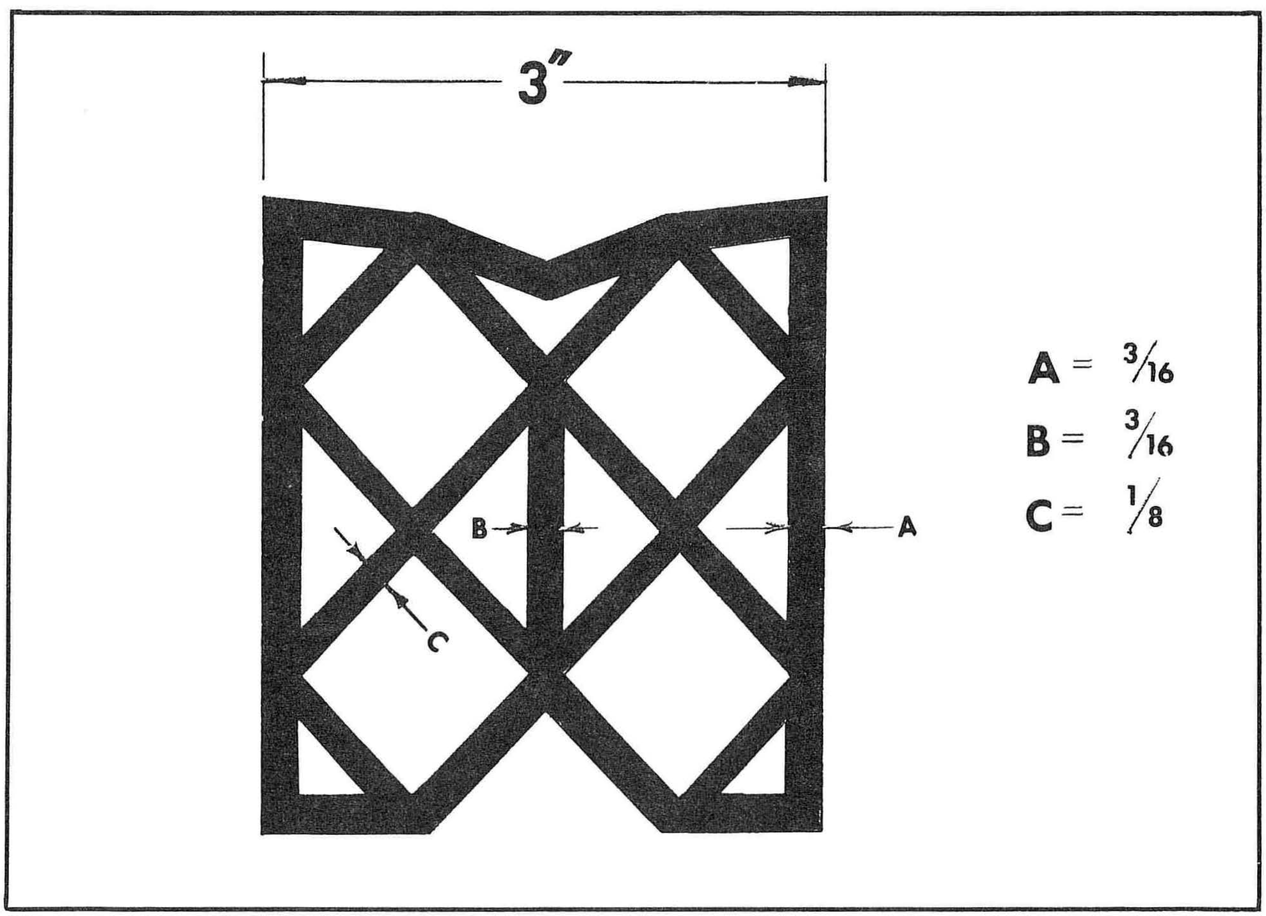


Figure 11-C. Field proven heavy duty bridge configuration.

	1-1/4 to 2" Seals	2-1/2" to 6" Seals
Minimum Pressure at 85% Compression (compressed 15%)	3 psi	4 psi

Pressure generation for bridge compression seals should always be measured per square inch; never in pounds per lineal foot.

DEPTH TO WIDTH RATIO

A depth to width ratio has been established from long term field experience and repeated condition surveys of seal performance. Proper seal depth is necessary to provide the desired area of interfacial surface contact, friction and to maximize a seal configurations ability to resist vertical migration. Most important, this depth ratio must be maintained to achieve leakproofing. Time dependent post installation interfacial spalling, edge attrition, dry shrinkage cracks, microcracking, interfacial cavitation, etc., necessitates that a maximum amount of surface contact area be provided.

Specifications should require that the depth to width ratio for a bridge compression seal should never be any less than 1-1.

The rapidly moving tendency towards a systems approach to sealing where more than one seal is used in a modular system requires that the above pressure generation minimums and depth to width ratios be maintained in order to produce a force sufficient to move the separator plates without distortion through their stroke of movement.

ROTATION, DEFLECTION AND THRUST MOVEMENTS

Some typical movements that can occur in bridge joint environments other than straight thermal opening and closing which must be absorbed by seal configurations are illustrated in Figures 11-D; 11-E and 11-F.

Individual seals as well as modular and multi-modular systems must have the ability to accept rotation of interfaces (Figure 11-D), resist alternating vertical deflection motion (Figure 11-E) and maintain their structural integrity under differential thrust displacements (Figure 11-F) without walking upwards, buckling of top portions, etc. Light webbed seals with little pressure generation have not worked well in the above types of movements while the heavy duty shapes shown in Figure 11-C have proven themselves thoroughly on thousands of bridges throughout the free world. The basic seal design should be structurally adequate and exhibit its ability to maintain constant contact with the top edges of both joint walls during its full range of movement without misalignment or pulling away. There is an absolute necessity to field test a seal configuration over a number of cycles of weather in a multiplicity of bridge joint environments to prove its performance capability under the above movement eccentricities.

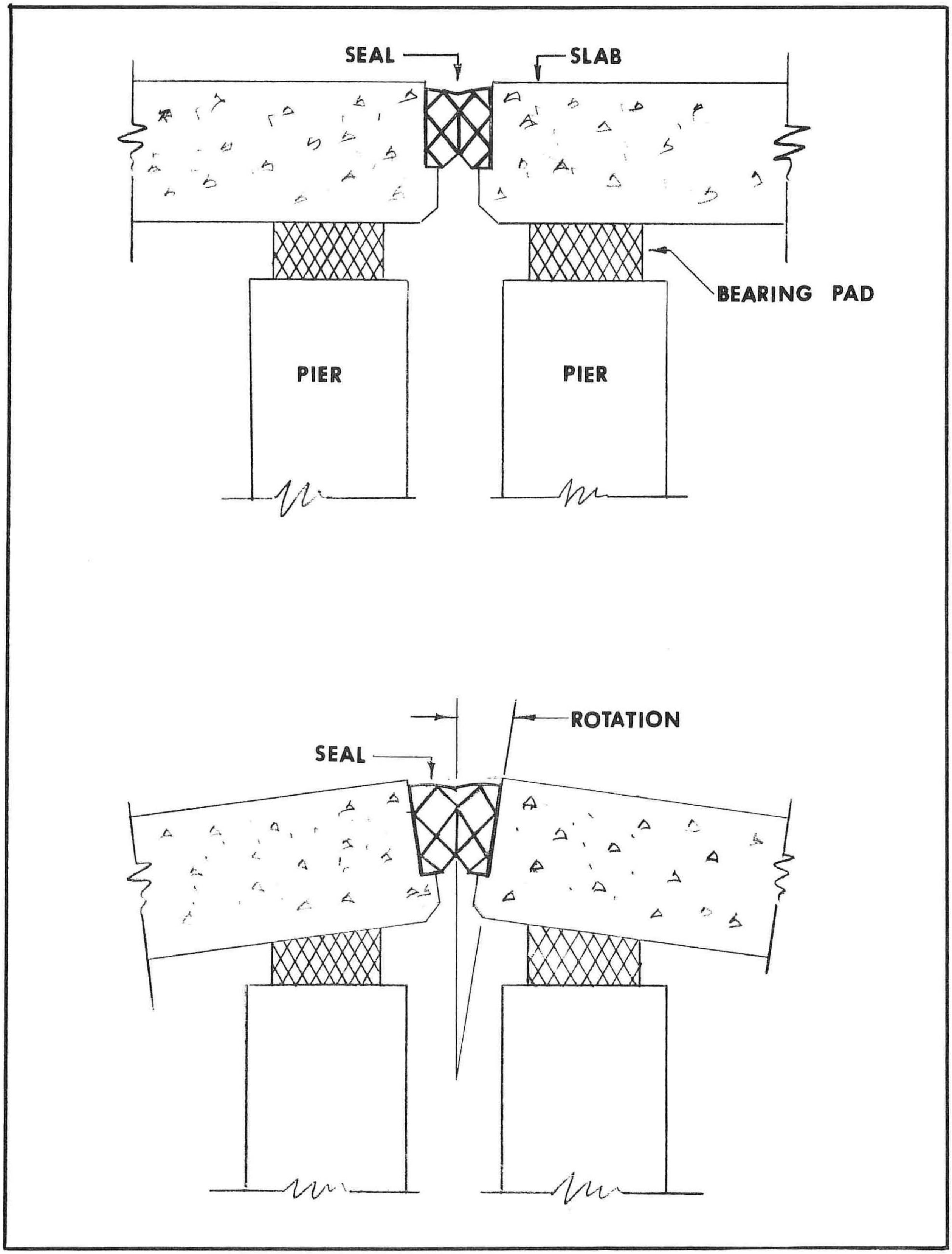


Figure 11-D. Typical rotation movement.

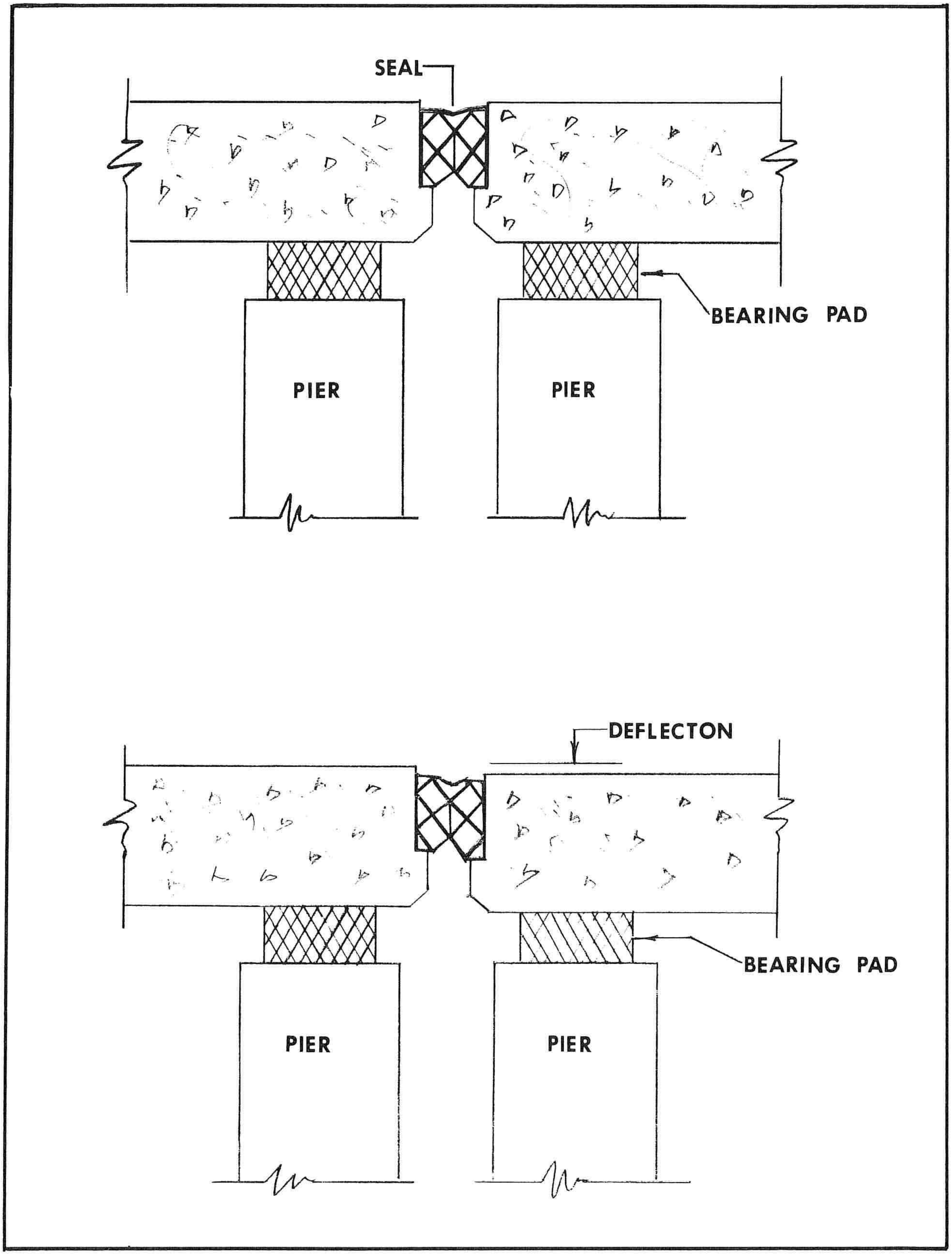


Figure 11-E. Typical deflection movement.

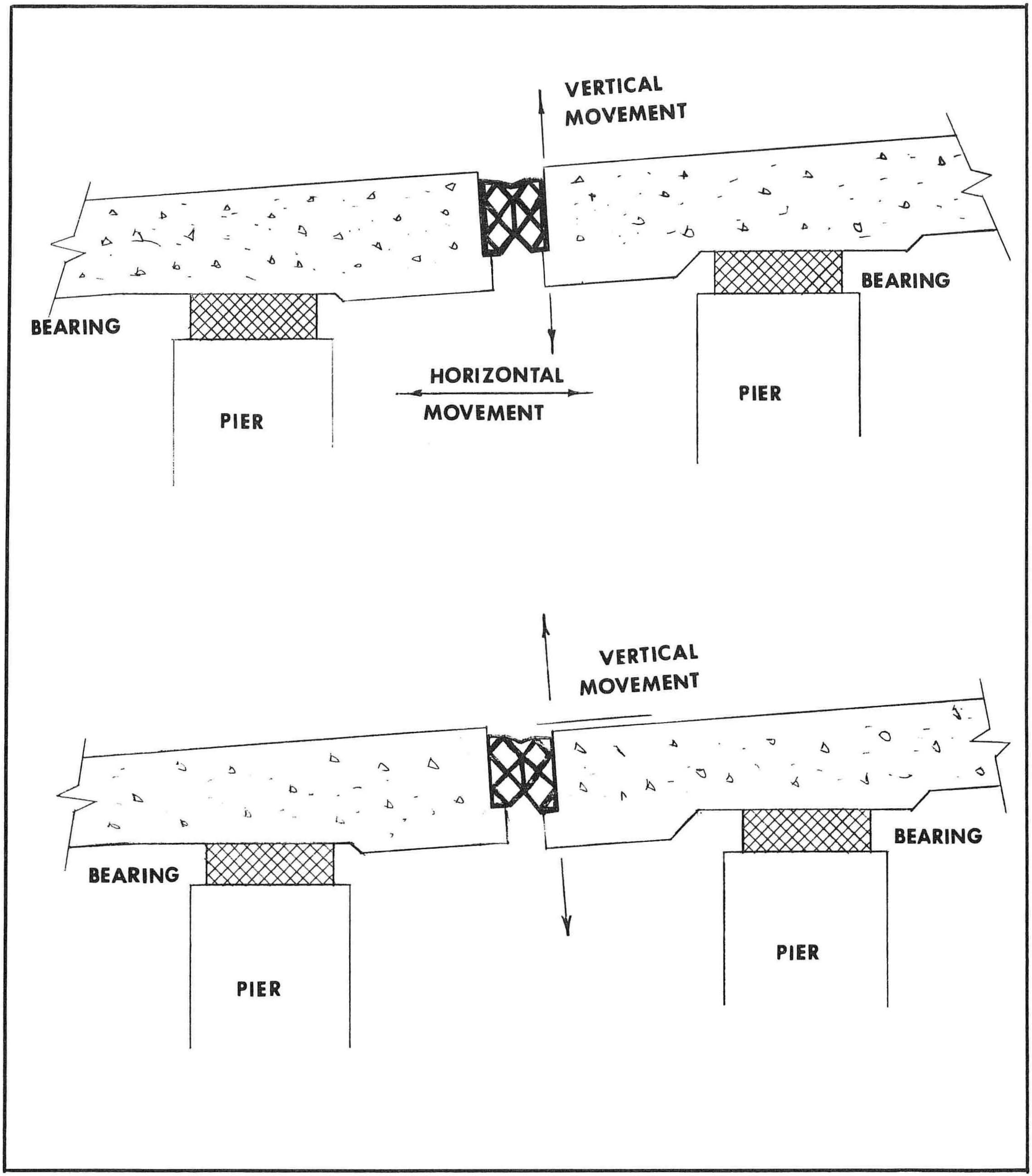


Figure 11-F. Typical horizontal thrust movement in an inclined plane.

Watson, Stewart C.

SOME SOLUTIONS TO THE PROBLEM OF VERTICAL FORCES

Figure 13 shows the latest 1969 specification requirement of the Bridge department in the State of Utah for compression seals utilizing a seal cleat. A mating groove is machined into the joint armour as a solution not only to potential vertical migration, but as an improvement toward leakproofing. One unique feature of the Utah System is to maintain the cleat location at the same position with respect to the riding surface so that as seal sizes and joint widths change from bridge to bridge, the cleat position remains vertically constant. It has been the experience in this state to find that prestressed bridge decks in a number of cases have sustained time dependent shortening, probably due to creep, and this has after long term service necessitated replacing some joints with larger size seals.

Figure 14 shows a Swiss-German solution now in wide usage throughout central and south central Europe, consisting of cantilevered plates which in addition to preventing upward vertical movement of a seal, also solves the problem of excessive joint width. The extent of the cantilever is limited to and must reflect the compression limits of the specific seal configuration being employed.

There now have been developed methods of mechanically locking a configuration into place to preclude migration in either direction. A secondary effect is to provide positive performance in long term usage of organic elastomers, the very finest of which over extended periods of in-service usage, would exhibit a gradual stress-related pressure decay. A third effect would be to practically guarantee a 100% leakproof joint.

The importance of utilizing a good, high solids, adhesive system with bridge type compression seals must be underscored. It is now possible with the new type adhesives that have been developed for compression seals to positively affix a seal to the joint interfaces with reliability. A recent example on the State of Louisiana Pontchartrain Lake comparison field tests of sealers clearly illustrates the importance of good adhesive systems for bridge compression seals. Due to differential friction on bearings, movement unloading occurred with the result that occasional joints moved in excess of the uncompressed width of some compression seals by as much as 1/4 inch. (Joints opened to 2-1/4" where a 2" wide seal was installed.) Still, certain compression seals which had been installed with the new high type lubricant-adhesives are performing effectively today because of being actually bonded in place. It should be the design goal of bridge specification writers to produce a rubber tearing bond whose strength would be such that it would require a hammer and chisel for its removal. Since we can not always predict with reliability the movements that will come on any type of structure, it is logical that we should use high type lubricant-adhesive systems.

DETERMINATION OF DECK TEMPERATURES

The success of any attempt to install a sealing system without giving attention to temperature-joint width considerations would be analagous to success at Russian roulette, being hit or miss at best.

It is therefore a necessity, particularly on longer spans, to make a reliable judgment of the temperature of a given bridge deck or span in order to activate the sealing system,

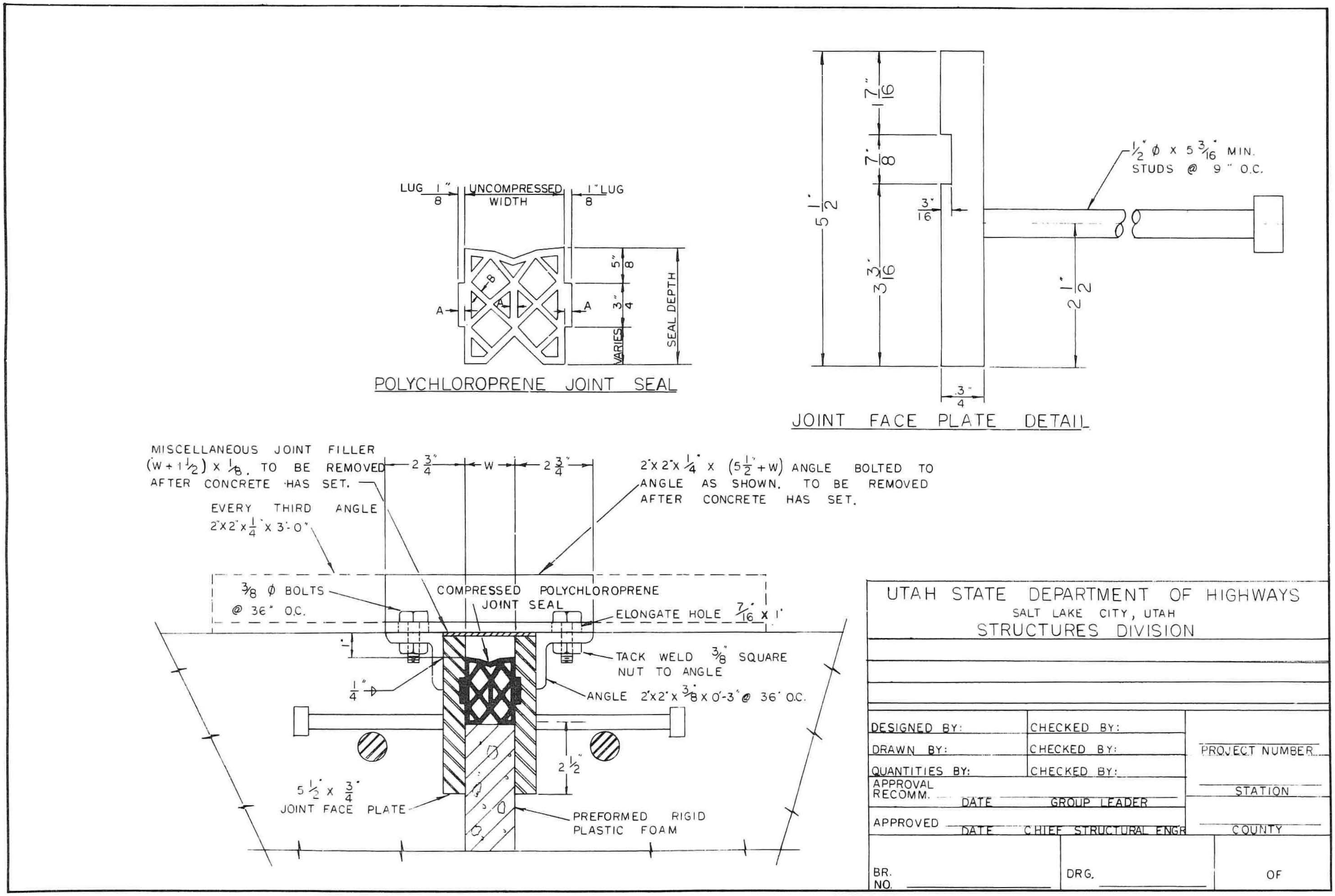


Figure 13. New State of Utah design incorporates seal cleats.

ideally, at the precise temperature of the span. This judgment can be rather complex as evidenced by the work of T. Wah and R. Kirsey [1] in a report entitled "Thermal Characteristics of Highway Bridges" (Southwestern Research Institute - March 1968). In early Spring or late Fall, air temperatures and deck temperatures can differ 50 degrees due to temperature lag.

Obviously, complex instrumentation could be implemented through which the temperature judgments might be made. However, Messrs. Wah and Kirsey have indicated the pitfalls involved and the many variables that are possible.

It would be most desirable to be able to take the deck temperature without relying on complex and potentially unreliable as well as costly instrumentation.

Since European bridge designers have been working for some time with longer spans, some actual working practices are included hereafter.

British Ministry of Transport-Road Research Laboratory.
(Tech. Memo (Bridges) No. B. E. 6)

A measurement of shade air temperature beneath the deck at the time of setting a joint, or in the case of box girder construction, a measurement taken inside, will give an indication of the mean bridge temperature to within $\pm 5^oC$ ($\pm 9^oF$). This is normally sufficiently accurate for setting an expansion gap capable of accommodating horizontal movements of up to 5", but when further accuracy is required, thermo-couples or thermometers at representative points within the structure can reduce the error to $\pm 2^oC$ ($\pm 4^oF$).

German-Swiss Engineer-Contractor Firm

A small copper tube with its lower end squeezed or closed is imbedded in the concrete at different locations after which copper constantan thermoelements are placed inside incorporating millivoltmeters with electronic temperature writers. A standard temperature element serves as a base for comparison (Example - iced water of constant temperature). The millivoltmeter is used to measure the voltage between the equalizing element located in the melting ice water and the elements located in the concrete.

BRITISH CONTRACTOR SPECIALIST

A very simple system that is in use by one active British bridge expansion joint installation firm is to construct a small plaster of paris dam in a shaded area, fill it with water and place a thermometer in the water.

Watson, Stewart C.

ADJUSTING SEALING SYSTEM TO DECK TEMPERATURE

Once a deck temperature judgment has been made, the sealing system is then prestressed to correspond (i.e. opened to 40°F or closed to 90°F) accordingly. Figure 16 illustrates a typical temperature-width chart used in prestressment of a sealing system. A sealing system that is not properly activated at correct temperature-width or one that does not include this consideration in its design is capable of self destruction, damage to the bridge or a combination of the two.

PLACEMENT OF THE SYSTEM IN A DECK.

Two methods of placement exist, the blockout method or casting in place method.

Blockout Method

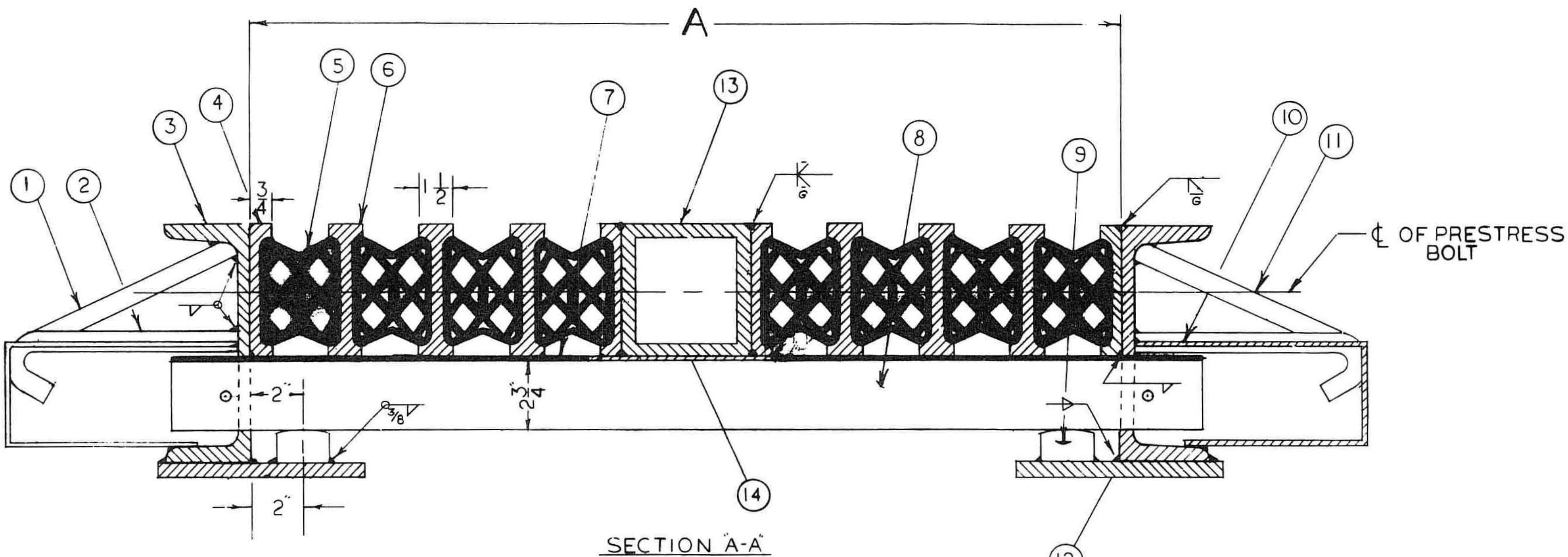
This appears to be the safest method and is probably preferred since it is the simplest and eliminates many problem areas in construction. There is the consideration of having a construction joint at the blockout but recent improvements in placement methods have operated to solve the ridability, concrete to concrete bonding, and leakage difficulties.

Figures 17-A & 17B show a modular system with a 6" movement capability which has been set for temperature-width and is now being welded to the main reinforcement of the bridge deck. This offers ideal performance since the system now has become a part of the bridge structurally. The excellent ridability obtained by this method is very simply and positively achieved by means of low cost, recoverable, positioning support members, which, longitudinally span the blockout and accurately suspend the sealing system while the concrete is being placed.

Cast In Place Method

This method has the advantage of eliminating the construction joints that are a part of blocking out however it presents opportunities for aborting the system if field personnel are unfamiliar with the intricacies of these somewhat sophisticated sealing devices.

Once a sealing system has been prestressed for temperature width and fixed for placement, the threaded rods, centroid to the device, must be removed in order for it to reflect the anticipated movement eccentricities of the structure. It then becomes obvious that the setting of the proper prestressment, the fixing of the device and the placement of the concrete must necessarily be in concert with elevating thermo-centripetal displacement. In plain language, prestressed sealing systems should be installed and placed beginning in the morning or as the deck temperature is rising since the prestressment mechanisms will then self-loosen themselves for ease of removal. An improvement to single module and modular systems has now been developed which would permit some slab end regression such as would be occasioned by a dynamic temperature drop (cold front moving in) excessive wind-chill effects, inordinate creep or shrink, etc. prior to relieving or activation of the prestressment mechanism.



DIM	MIN	MAX	30°	40°	52°	60°	70°
A	21.25	33.25	29.823	28.680	27.766	26.394	25.251

Figure 16. Temperature-width chart for prestressment of a sealing system. (12" movement) Williamette River Bridge in Oregon.

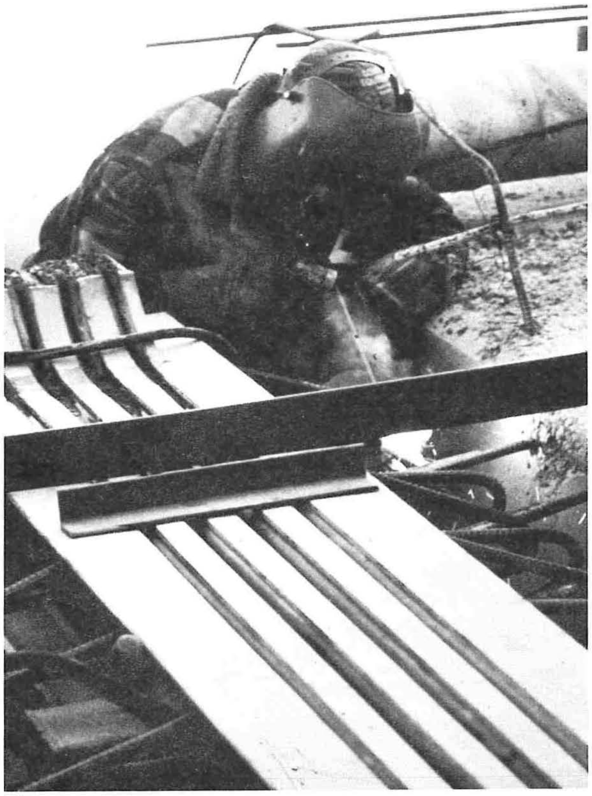


Figure 17-A. A four-tube (6-inch movement) modular system being welded to the main reinforcement of a post-tensioned concrete bridge.

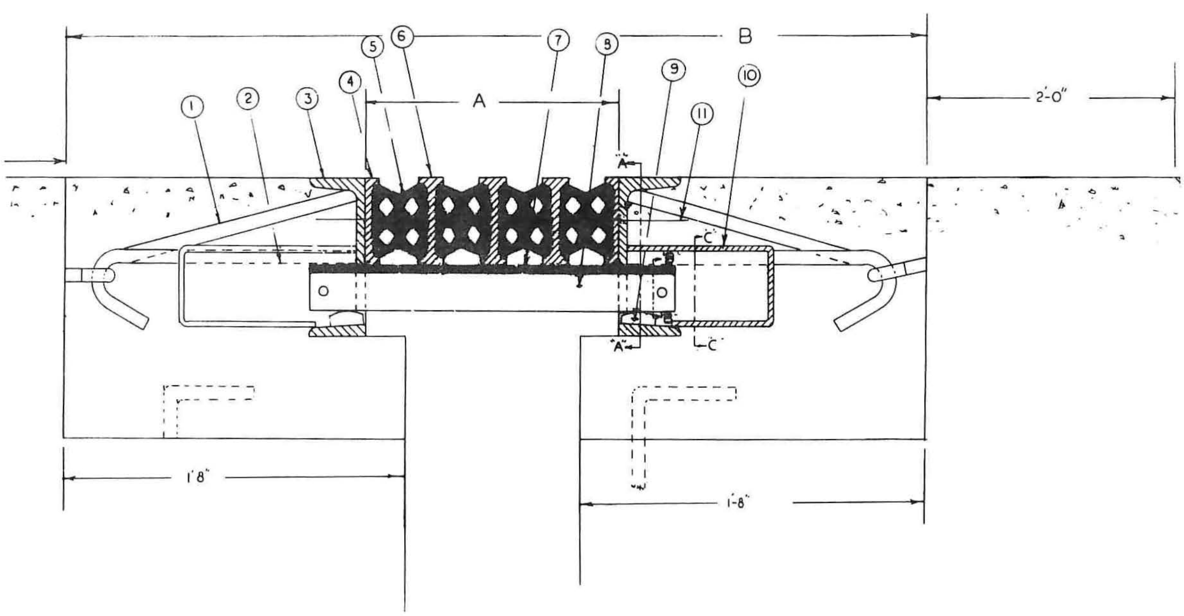


Figure 17-B. Plan view of 4-tube, 6-inch movement modular system.

PROTECTION OF A SEALING SYSTEM DURING CONSTRUCTION

Rigid ramps capable of carrying all construction traffic should be maintained over a blockout. If the system is installed way in advance of the completion of construction work, the jointing system should be similarly protected since the worst possibility for damage insofar as heavy loads, high concentrations of foreign material, etc. are present while construction work is in process.

The exposed surface of the sealing system should be protected during placement of concrete to prevent unsightly contamination and costly cleanup.

All imbedded surfaces should be kept free of chemical contaminants. Some interesting new data on corrosion producing factors heretofore not commonly considered to be at typical construction sites has been exposed in a recent work by Szilard(2).

CHANGING A SET OF MODULAR LAMINATIONS.

If in the service life of a bridge, unanticipated time dependent movement, subsidence, pier shifting, etc. should require a performance need in tension or compression in excess of the design limits of a modular system that is in place on a structure, it is now possible to convert the device by either adding or taking out laminations and tubes as the need dictates.

The entire modular package can be removed by temporarily tack welding a horizontal bar across the top during high compression stress (mid-afternoon), after which side welds and tubes would be ground open and the laminations with the tubes lifted out utilizing a synchroneous hydraulic device. (See Figure 18). The modified modular package would be replaced in reverse order.

In massive traffic jams, the public does not always necessarily understand the design complexities of our modern bridges and since an uncomfortably high incidence of unpredictable movements is occurring on some of our newer long span bridges, this convertability of modular systems is a most desirable factor in its design.

IMPROVED BEARINGS AND THEIR RELATION TO THE SEALING PROBLEM.

With respect to the new continuous bridges of longer spans, the old rigid plus the newer elastomeric bearings have definite structural, rotational, unilateral, multilateral and longitudinal movement as well as height and economic limitations.

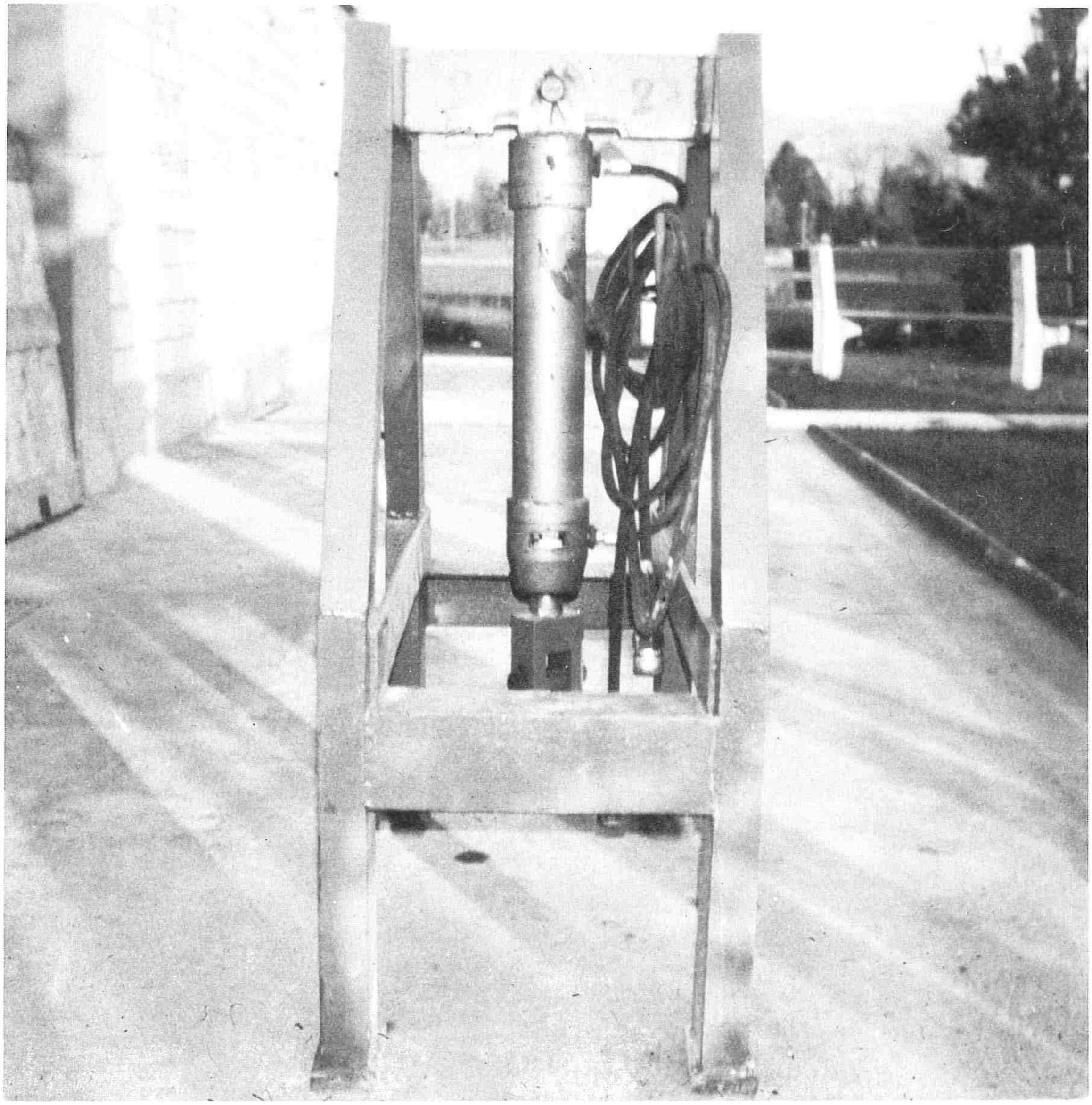


Figure 18. Synchronous hydraulic lifting device.
(Swiss-German)

Particularly with longer spans where higher loads and significant displacements occur, the design of the bearings and the design of the sealing system should be inter-related. Some examples of new improved bearings currently in wide usage in Europe and Canada are illustrated in Figure 19.

The new pot bearings were developed in Germany and are designed to minimize strains on a structure as well as its foundations, eliminate undesirable friction and costly maintenance by utilizing primarily inorganic materials, stainless steel, etc. A typical pot bearing consists of a rubber disc set inside of a shallow piston/cylinder assembly. Behavior resembles a hydraulic cylinder containing a viscous fluid. Since rubber is in reality a liquid, the neoprene used in this application cannot be affected by prolonged stress since it is actually taking the place of the oil in a piston assembly. This allows the bearing to accept rotation with negligible shift in the center of pressure. For unilateral and multilateral bearings, one face is equipped with a P.T.F.E. (Teflon) pad sliding against a polished stainless steel plate permitting horizontal movement. The resulting sliding friction coefficient of 1% or less permits lowest bending moments and shear forces.

Bridge engineers should proceed with caution in the selection of bearings incorporating fluorocarbon sliding surfaces. Certain new designs have recently appeared wherein horizontal forces and frictions resultant could produce a crushing overstress to the fluorocarbon. Further than this, the concrete stress in the outer area of the bearings can become dangerously high. One should be suspicious of the calote type bearings where horizontal forces are absorbed in the outer sector of the bearing only and not centered. For this reason, in Germany today, the use of calote type P.T.F.E. bearings is not allowed.

NEW PROBLEMS IN JOINT SEALING

The advent of the studded tire and its effect on pavement and bridge surface materials can no longer be ignored. Canadian engineers have recently exposed and called attention to the fact that as much as 1/4" of cement concrete in the traffic area profiles of concrete pavement is being ground away in as little as 90 days of service with approximately 10% of cars in the Toronto area being equipped with studded tires. Since it is anticipated that during 1969, the life saving popularity of studded tires may be increased from 10-25% of all cars, one can readily surmise that a serious problem exists. Other states have recorded similar experience. (See Figures 20-A, 20-B, 20-C).

Similarly with the advent of tungsten carbide tipped snow plow blades which appear to be ideally suited to removal of snow and ice, so necessary for keeping people alive at high speeds, a monstrous new problem exists for the bridge engineer. At high

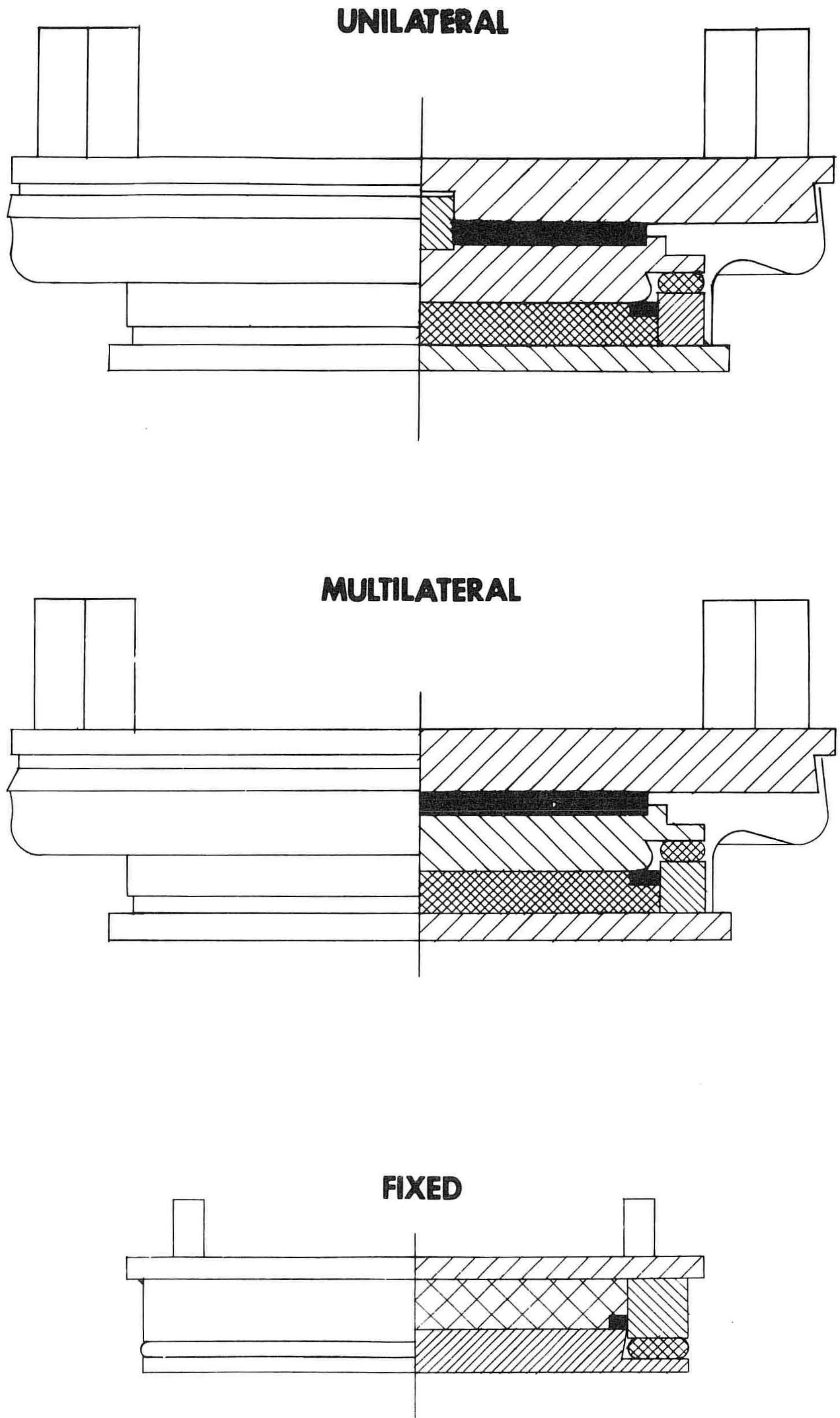


Figure 19. New type bearings minimize strains on structure and foundations, eliminate friction and costly maintenance. (Gutehoffnungshütte-Germany)

Figure 20-A. Typical studded tire attrition.

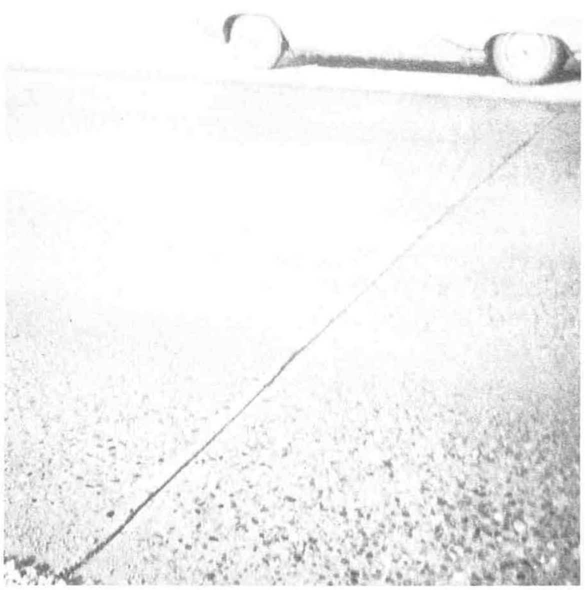


Figure 20-B. Valleys produced by studded tires accumulate deleterious salt brine.

Figure 20-C. Studded tires break down joint edges prematurely.

speeds, these snow plow blades which bounce and scrape away at anything in their way that is less potent than tungsten carbide, can rip out and shear off any type of armor, elastomer or concrete in its path with little or no difficulty whatever. Figure 21 illustrates an armor plated joint less than a year old completely folded over by a high strength steel blade.

Since snow removal at high speeds is a design condition, permanent time dependent changes in any portion of the elevation of a bridge are now vulnerable to dynamic shear forces. Figures 22 & 23 show a change in elevation of one side of a joint on Bendorf Bridge over the Rhine River in Germany, probably due to an increase in dead load deflection on what represents the world's longest post tensioned span to date.

SPECIAL DESIGN FOR SNOW-ICE ENVIRONMENT

Since jointing systems on bridges in snow and ice areas are more vulnerable to the increased demands of this environment, special attention in design is obviously a necessity.

It would appear logical that all exposed surfaces of the jointing system should be lower than the riding surface of the deck by 1/4 inch. In addition, all exposed corners or edges should exhibit a radius. Special attention should be given to salt brine attack and vulnerable portions of the system should be designed for ease of replacement should unusual damage from plows occur.

In very low temperature areas where temperatures are considerably below minus 20 degrees F for sustained periods of time, the seal lock concept should be given consideration.

MODULAR SYSTEMS AND DAMPING EFFECT.

Interest in orthotropic bridges has increased greatly on the American continent and a number of structures utilizing this design currently under construction are incorporating modular and multi-modular sealing systems not only for their ability to perform with adequacy under large longitudinal displacements but because of their natural damping effect in compression.

Obviously welcome economies are incumbent through orthotropic designs but an inherent loss of stiffness and responses of these decks to the forces of excitation offer a challenge to the designer of the jointing system.

The Halifax-Dartmouth Narrows Bridge has specified a multi-modular system for the expansion joints under the main towers with a performance requirement of 18 inches in longitudinal movement and its resultant damping effect is expected to contribute toward a reduction in vibration on this orthotropic structure. (See Figures 24 & 25).

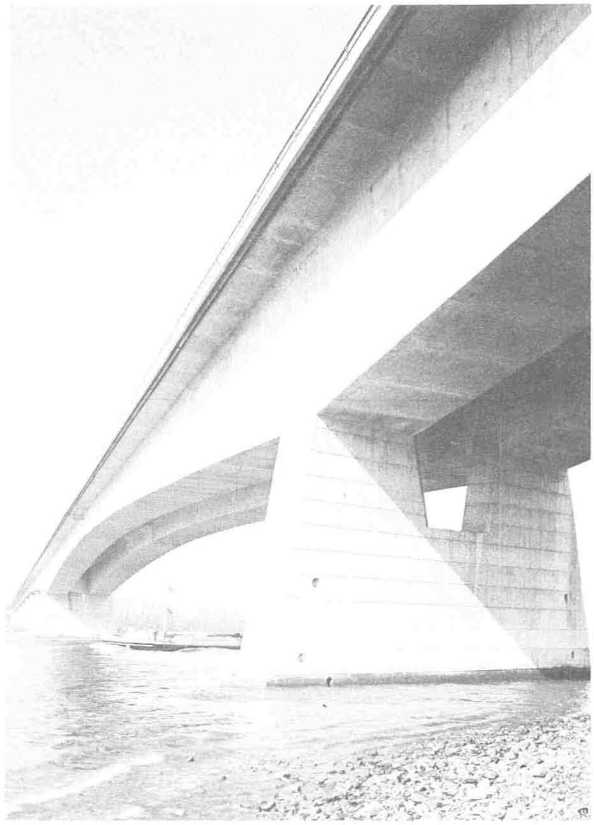


Figure 22. Bendorf Bridge in Germany-side view of world's longest prestressed structure.

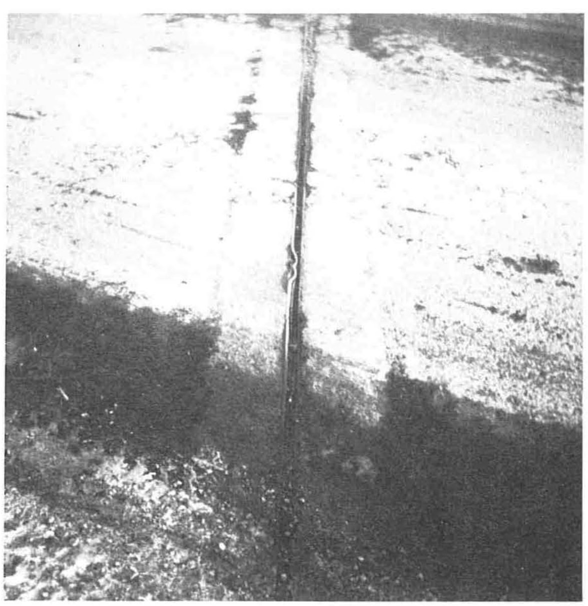


Figure 21. Snow plow damage to armor-plated joint.

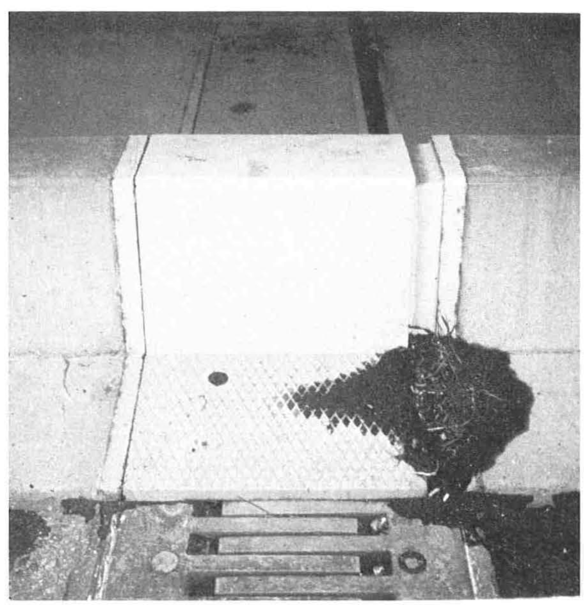


Figure 23. Permanent dead load rotational effect exposes armor to snow plow blades (Bendorf Bridge)

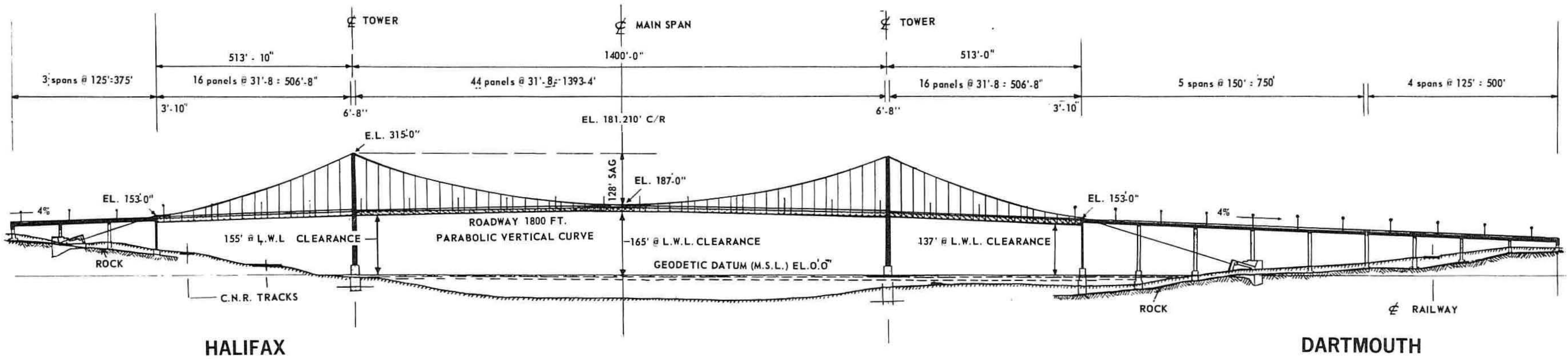
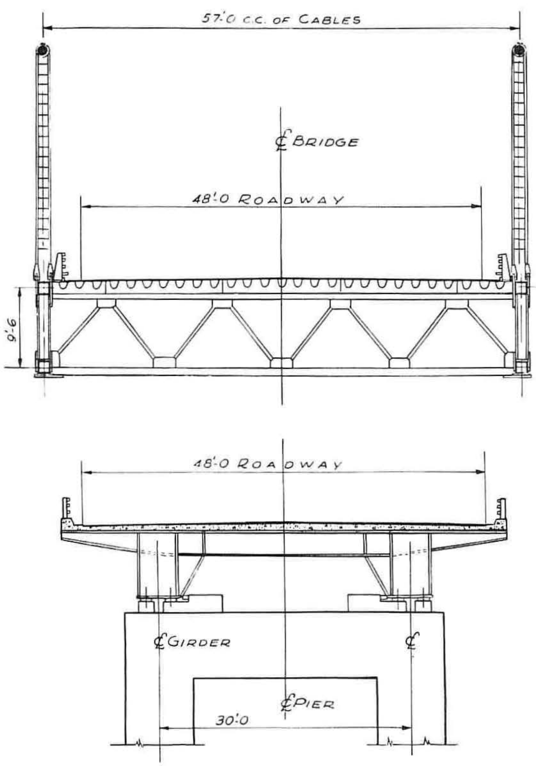


Figure 24. Halifax Narrows Bridge in Nova Scotia (orthotropic).



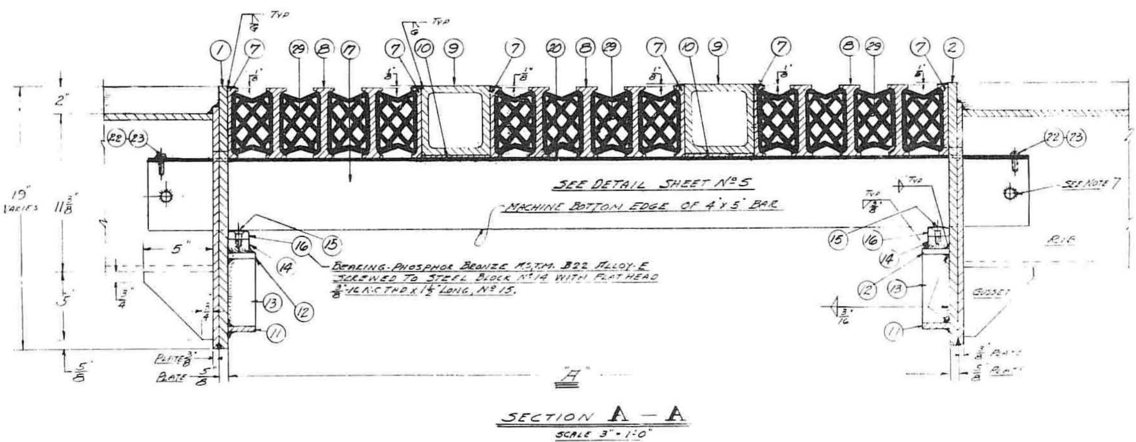


Figure 25. Modular sealing system incorporating 18 inch movement capability for Halifax Narrows Bridge.

Watson, Stewart C.

Papineau Bridge which will link the north end of Montreal Island with the mainland over Riviere des Prairies has been designed with cable stays utilizing two slender 126 feet high towers and an orthotropic deck, the center span being 336 feet. Aerodynamic model studies which have been conducted on this design have shown that vibrations of 2" amplitude could over a period of time be destructive while an amplitude of 9" during an extremely high wind could also be serious. Four modular systems with 9" of movement each have been designed for installation in this interesting Canadian structure. (See Figures 26-A & 26-B).

The Bayonne River Bridge in Quebec, first orthotropic bridge in North America to utilize a concrete wearing surface on its decks, has incorporated 4 modular packages, each with 4-1/2" of movement. (See Figures 27-A & 27-B and 28-A, 28-B, 28-C, 28-D).

CREEP & SHRINKAGE

Construction practice permitting, a modular system should be installed when most of the creep and shrink has taken place. When bridges are constructed of prestressed beams and in situ concrete, the rate and amount of creep appears to be difficult to calculate.

To a greater or lesser extent, under continuous loading, all materials of construction and all types of structures will incur irreversable dimensional loss (German Standard DIN 4227 October 1953). Shrinkage of a concrete structure, not to be confused with the lessening of a dimension due to creep, occurs mainly due to the moisture loss during curing.

A typical example of movement calculation follows using Swiss SIA Standards:

Assumed: Effective length of bridge 100m (332 feet).
Centric stress from prestressing - 60 kgs/cu.m.
Temperature at fitting of joint approx. +10°C
Modular System of 100mm (4" movement)

<u>Pre-adjustment of Modular System Calculation</u>

Creep	1.5 cm	
Shrink	2.0 cm	
Temp. decrease down - 10°C	2.5 cm	
Total shortening	6.0 cm	(Theoretical pre-adjustment measurement)
Temperature increase up to + 30°C	1.5 cm	
Effective displacement of joint	7.5 cm	
Reserve movement of modular system	2.5 cm	
Total movement of modular system	10.0 cm	

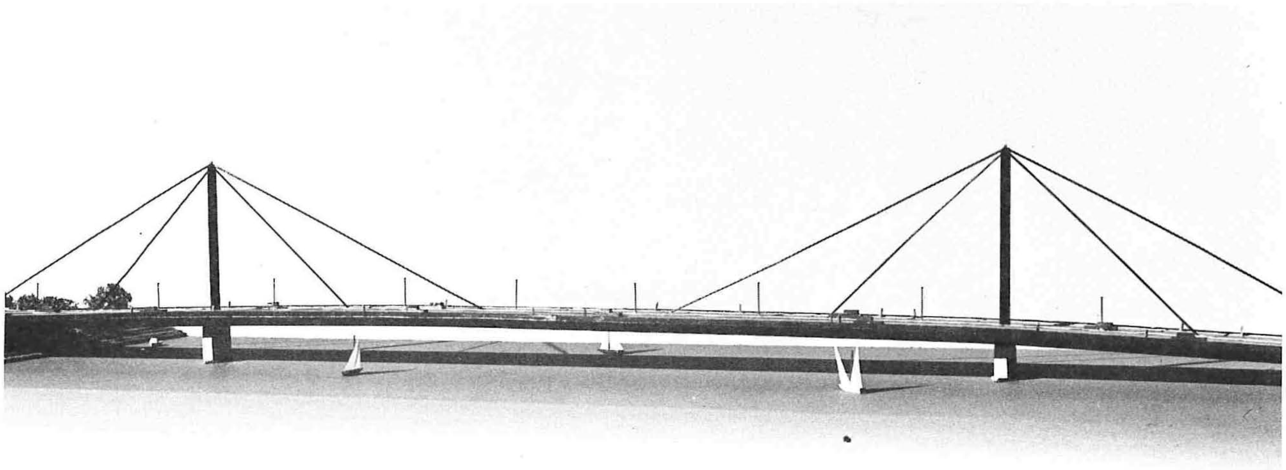


Figure 26-A. $~~10~~5, 000, 000 cable-stayed six-lane orthotropic Papineau Bridge over Back River at Laval, Quebec. (Gendron, Lefebevre and Assoc.)

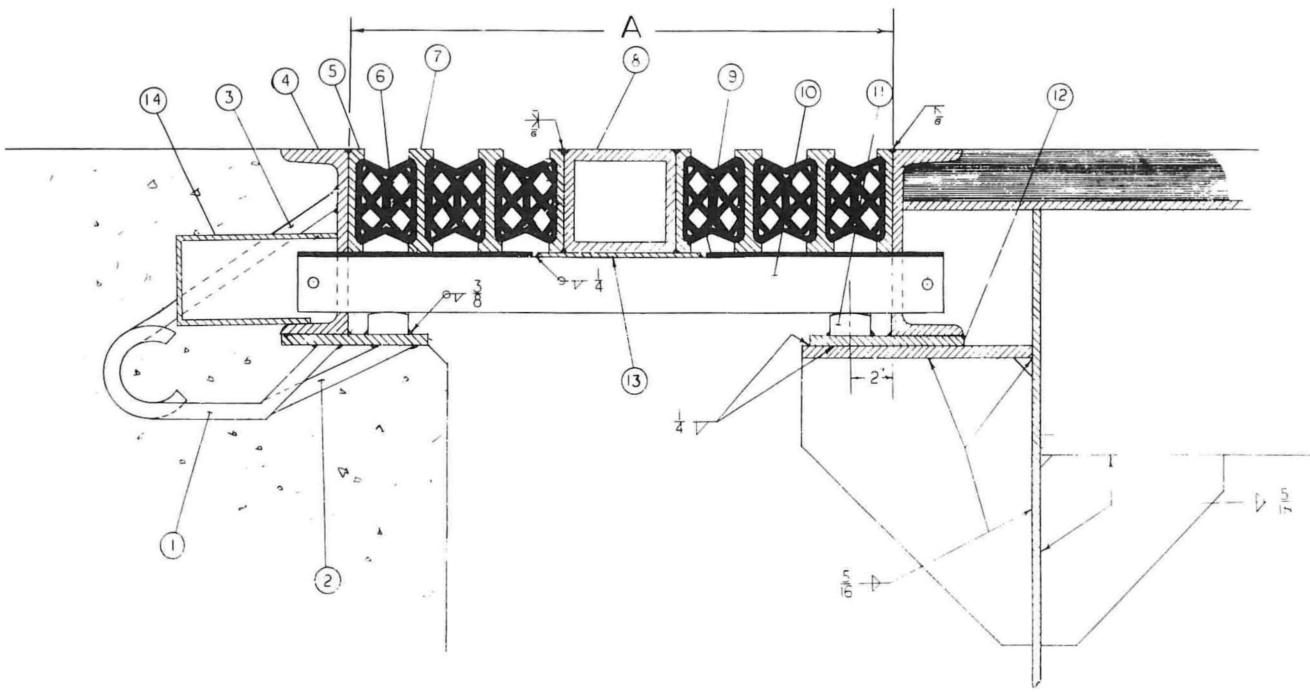


Figure 26-B. Six-tube modular sealing system for 9 inch movements on Papineau Bridge.

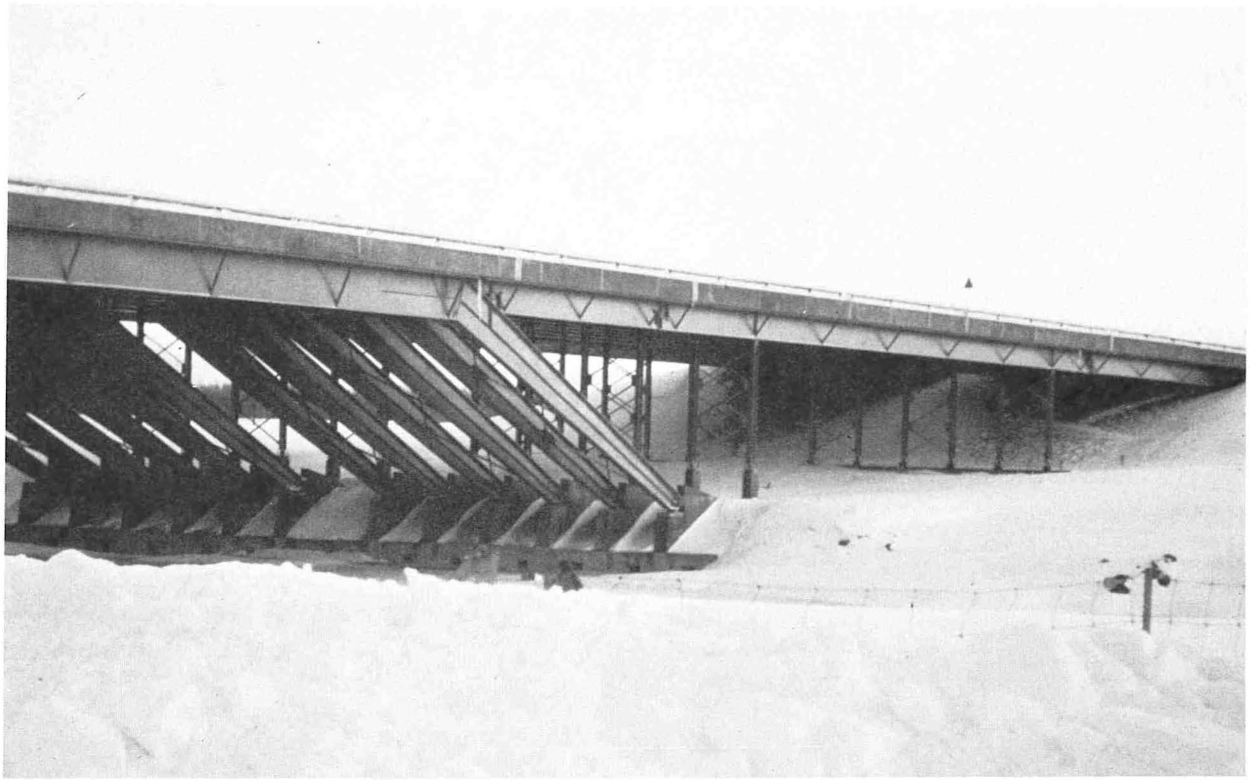


Figure 27-A. Bayonne River Bridge in Quebec is orthotropic with 4-1/2" movement at joints.

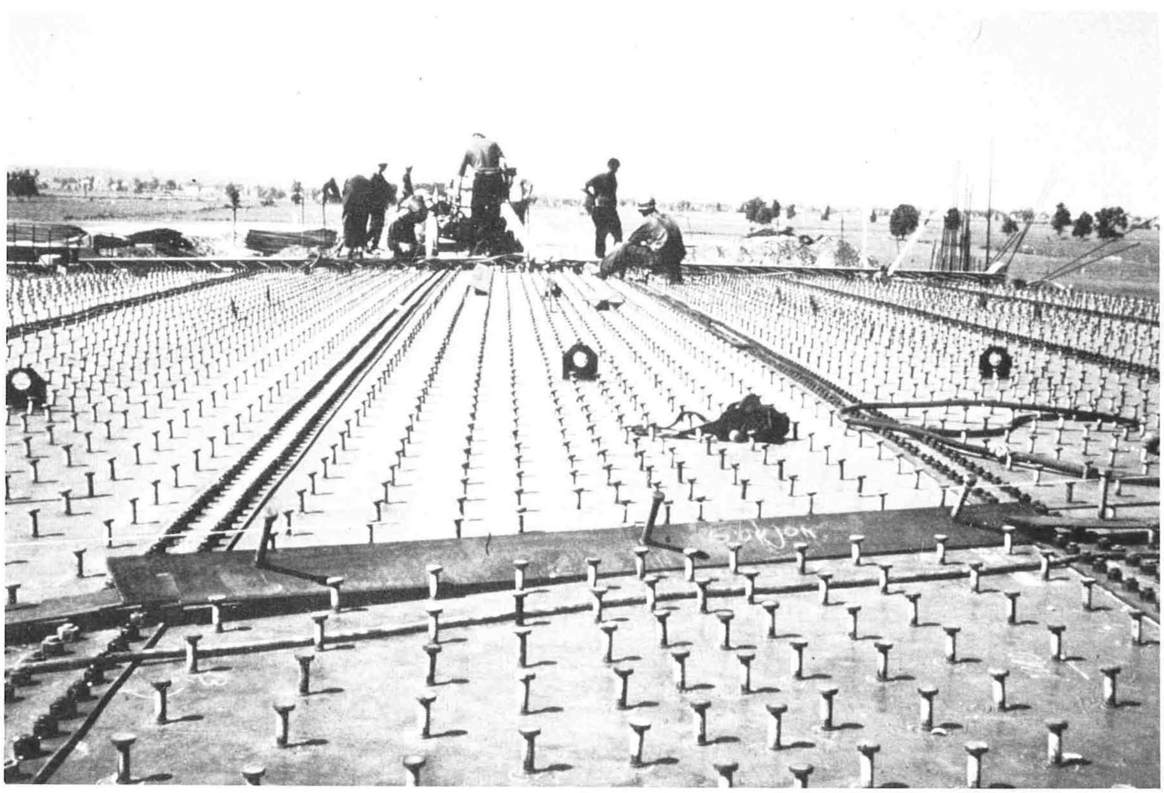


Figure 27-B. Battledeck with studs for concrete wearing course on Bayonne River Bridge.

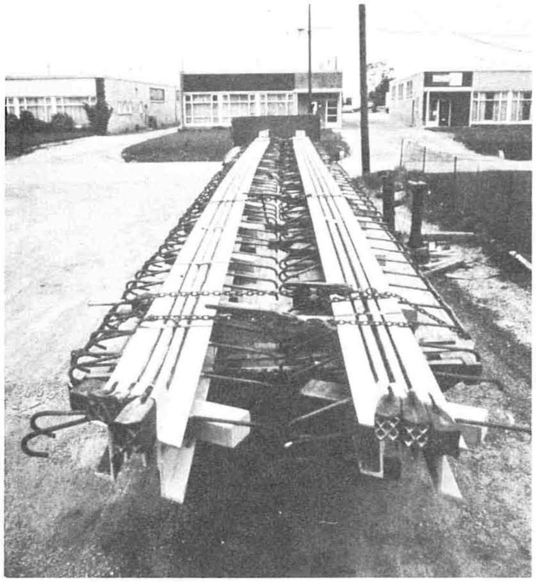


Figure 28-A. Modular sealing systems 48 ft. long in transit (Bayonne River Bridge).

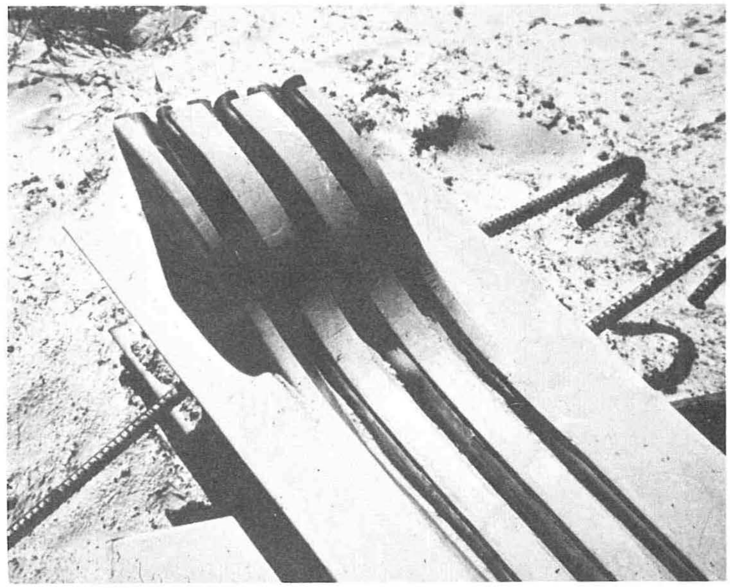


Figure 28-B. Modular system showing sculptured brush curb (Bayonne River Bridge).

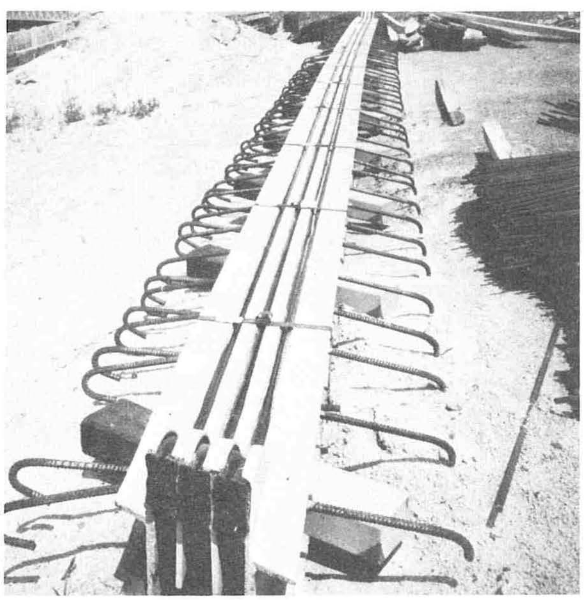


Figure 28-C. Modular system support members reflect 28 degree skew and differential camber in transverse profile (Bayonne River Bridge.)

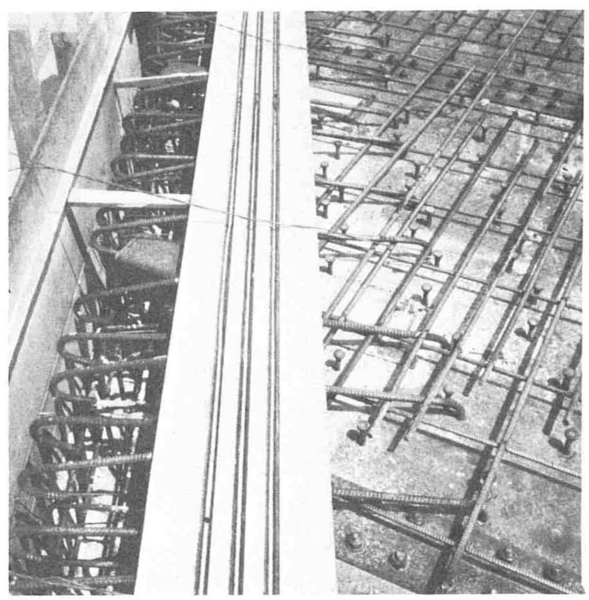


Figure 28-D. Modular system in place after prestressment for temperature-width prior to concrete placement (Bayonne River Bridge).

Creep and shrink have been widely discussed by authors of prominence, and it may be safe to say that the phenomenon is still not thoroughly understood or completely defined.

In view of this, it is of utmost importance to develop a practical, reliable, empirical method of creep-shrink calculation which works well for the modular system employed, construction method used, type, age and geometrics of materials, loads involved and environmental conditions, since the effects are irreversible and must be pre-adjusted at the moment of activation of any sealing system.

USE OF MODELS TO SOLVE SKEW PROBLEMS

Bridge design engineers have long persisted in changing direction in the line of a skewed joint at the curb line, which is a sound judgment structurally, however, it does pose the problem of having two entirely different types of movement within a single joint. It leaves the point of the angle at the change of direction particularly vulnerable to leakage as well as presenting two different width dimensions when cutting and joining at the curb line.

Sequence models have been built to trace the stages of construction for various curb and balustrade configurations that are popular with bridge departments as an aid in the solution of skew problems. Figure 29-A & 29-B show a four stage model of one state highway departments' curb and balustrade design which resulted in no change in the line of a skew so that the joint could be successfully sealed. Still, the outside appearance of the joints is architecturally as well as structurally attractive.

Much work has been recently done in the laboratory on skewed joints with compression seals and more is yet to come. Suffice it to say, skew joints require markedly different solutions than joints at right angles to the longitudinal centerline of a bridge. Figure 29-C illustrates a German solution for a skew which actually exceeded 90 degrees. The design of joint was armor plated, incorporated a compression seal and is 100% effective.

BRITISH MODULAR SYSTEM - RUNCORN-WIDNES BRIDGE

The Runcorn-Widnes Bridge was designed as a two-pinned arch, 1,082 feet between the main pins, the side spans being continuous, spanning the River Mersey, 13 miles upstream from Liverpool, England. Owing to limited construction depth at the end of the suspended deck, insufficient space was available to provide, at one point, lateral support, vertical support and an expansion joint. The suspended deck is nowhere positively restrained against longitudinal movement, the lateral bearing at each end consisting of a pin sliding in a longitudinal slot.

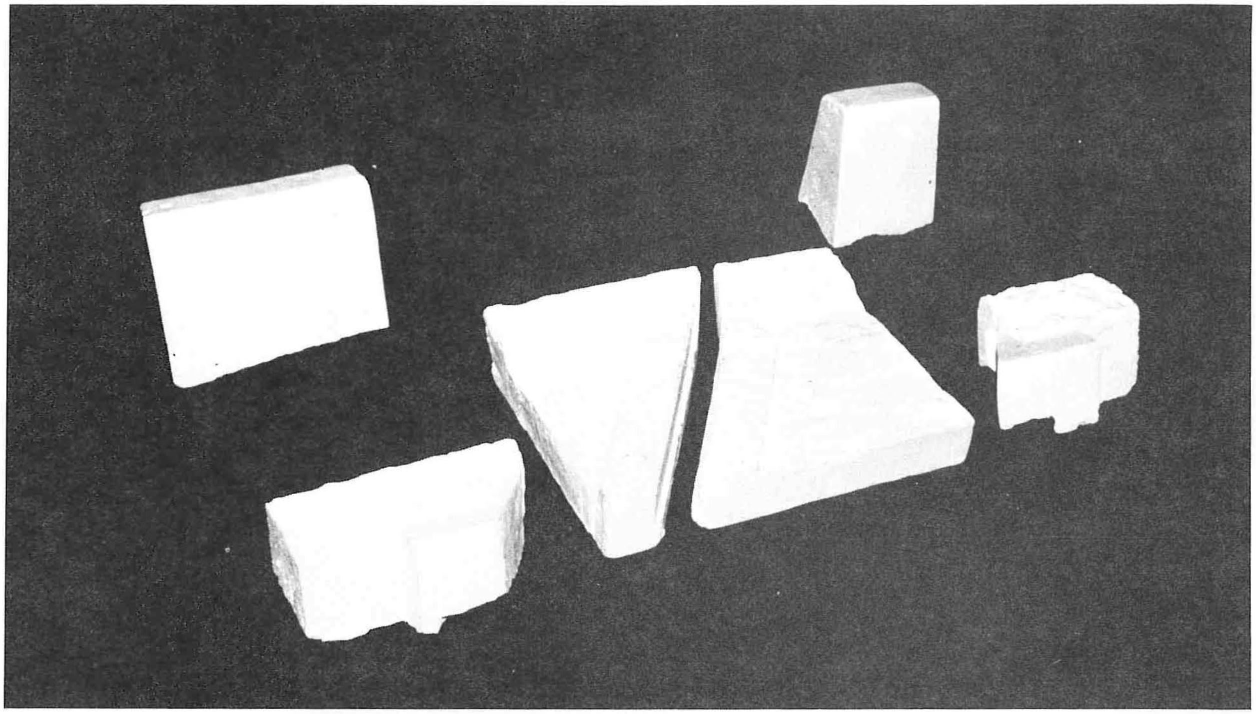


Figure 29-A. Four-stage plaster model illustrates method of construction for a skewed joint at curb.

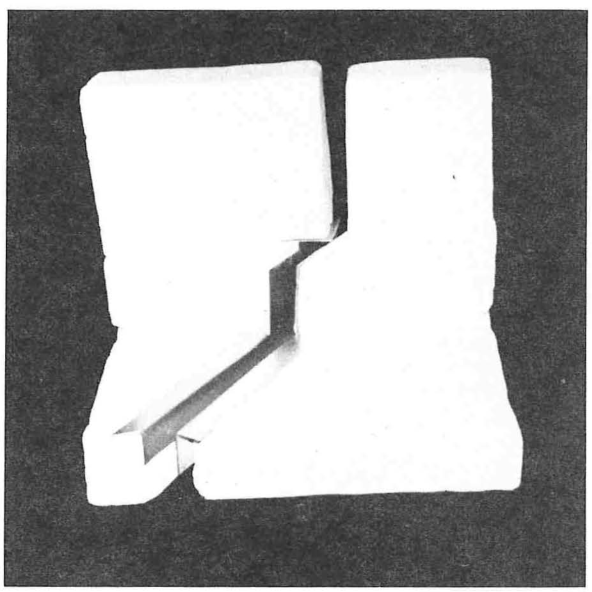


Figure 29-B. Assembled model of skew-curb shows elimination of change in direction at curb-line for effective sealing practice.

Figure 29-C. German solution to unusual skew problem utilizing compression seal.

The expansion joint being offset from the lateral bearing, has to allow for some transverse movement, slight vertical movement, longitudinal temperature movement, wind and braking forces. In addition it must act as a buffer to limit the extent of longitudinal movement.

To meet these requirements, the main expansion joint consists of 42 plates of medium manganese steel laid on edge across the deck, interleaved with solid rubber cushions. Each plate was delivered to the site with a pair of solid rubber cushions permanently vulcanized to it. The entire assembly, after being compressed together by jacking, opens and closes like an accordian remaining always in compression. The road surface is formed by the upper edges of the steel plates. Each unit can take up a movement of ± 0.1" with the entire assembly in combination being capable of ±4.2 inches. This movement is accompanied by a variation in compressive force of 2.85 tons per foot of width. The joint is watertight and a recent condition survey indicates it to be functioning effectively having originally been activated in 1961.

There are two secondary expansion joints made with dimensionally identical units, but in slightly softer durometer rubber. These allow ±.20 inches of movement per unit, with the same variation in compression force.

The object of using harder rubber for the main expansion joint was to provide a strong buffering effect against undue movement of the suspended deck due to braking forces. It was assumed in the design that a 45 ton specified braking force could act for long enough to bring 180 tons of vehicles to rest from a 30 mph speed and that any two of the three effects, (temperature, wind, and braking) could reach their maximum simultaneously. See Figures 30 & 31. (Photographs courtesy of Mott, Hay and Anderson).

Similarly, the cable stayed River Usk bridge in England has employed a modular system of somewhat lesser movement capabilities that has proven itself in service over the years. (See Figures 32 & 33).

AERODYNAMIC STABILIZING EFFECT

In late 1968 during a windstorm on the Bronx-Whitestone Bridge, (the World's 12th longest span - 2300 feet) varying aerodynamic pressure forces began to appreciably displace the bridge deck, both vertically and torsionally, so that self-excited oscillations (flutter) occurred, the magnitude of which panicked drivers into abandoning their automobiles resulting in a near chaotic condition. It is surmised that a modular system, properly designed, could improve on this apparent aerodynamic instability. (See Figure 34).

Figure 30. Runcorn Widnes Bridge over River Mersey at Liverpool, England is 1082 ft. long between main pins - opened 1961. (Mott, Hay and Anderson)

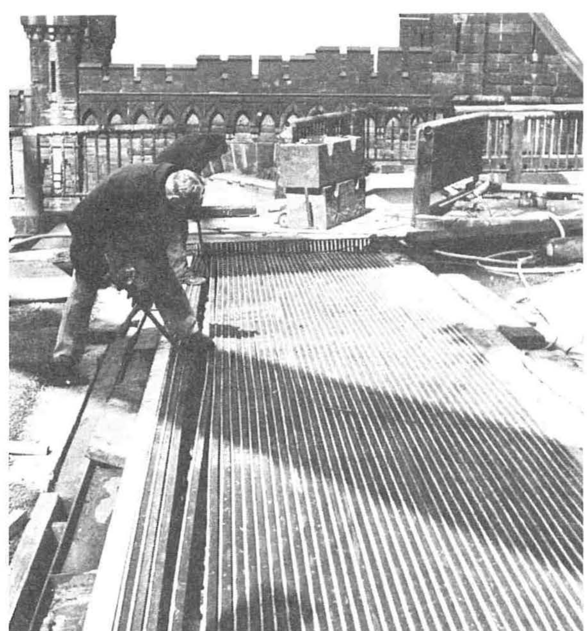


Figure 31. Modular system for Runcorn-Widnes Bridge.

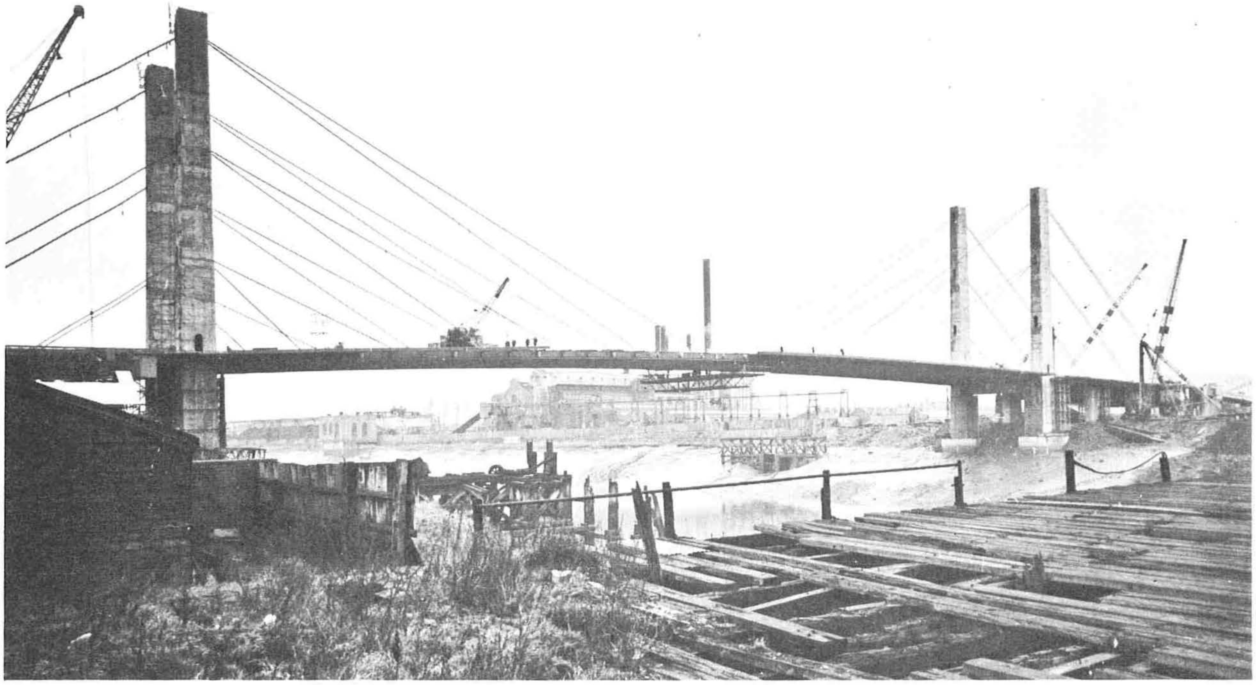


Figure 32. River Usk Bridge-England. (Mott, Hay & Anderson)

Figure 33. Modular system being placed on River Usk Bridge.

Figure 34. Bronx-Whitestone Bridge incurred severe flutter during 1968 wind storm resulting in near panic to motorists.

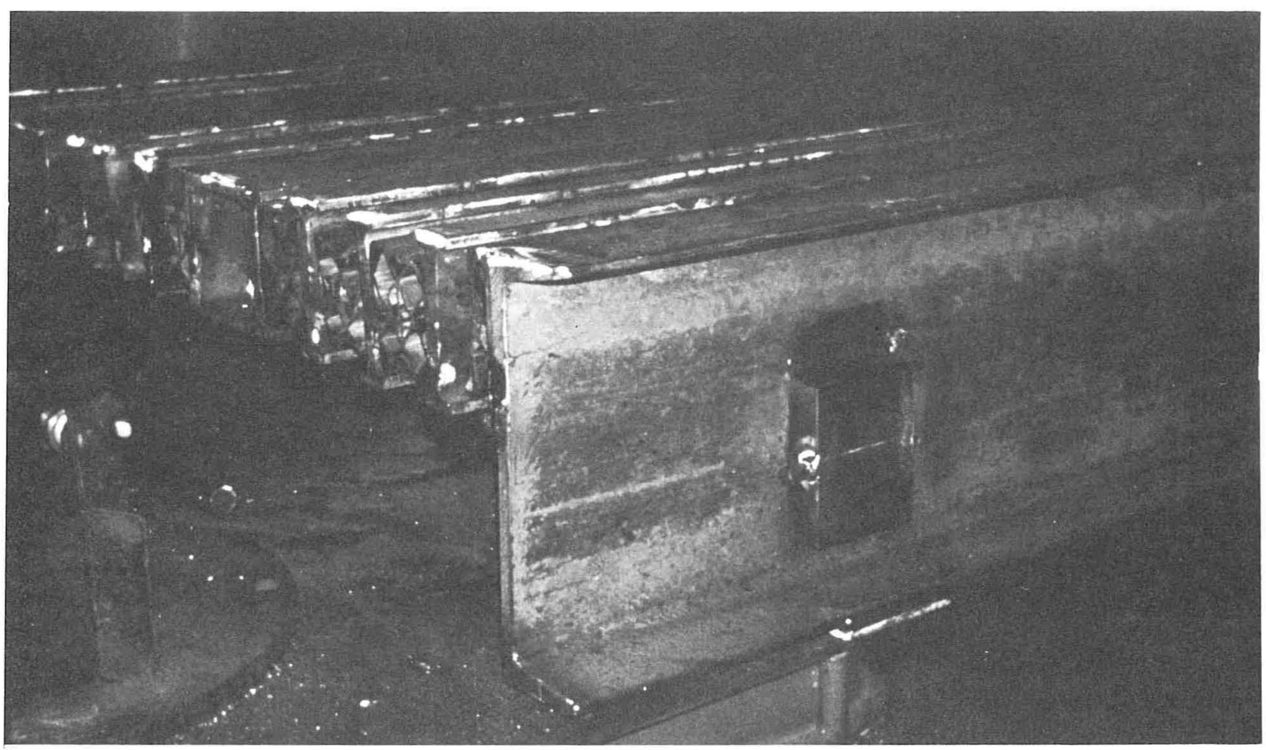


Figure 35. Full scale testing of an 18-inch modular system.

TESTING OF MODULAR SYSTEMS

While single module, modular and multi-modular systems can be fabricated for a wide range of movements and performance conditions, the assumption cannot be made that if a single module performs well, a four, eight or twelve tube modular system merely involves sandwiching up whatever elements are necessary to match calculated movements.

Full scale working sections should be run through their total anticipated ranges and types of movement in advance of fabrication to predict the reliability and practicality of a design.

Figure 35 illustrates a full scale working device, 6 feet long, built to accommodate 18" of longitudinal movement.

Since there are no known sealing devices exceeding 12" of movement in service today, one should be technically suspicious of a device or design until it has proven itself in service.

SOME TYPICAL MODULAR SOLUTIONS

Florenceville Bridge.

This lovely horizontal curved prestressed concrete structure, built in four sections using the BBR System, spans the turbulent, ice jammed St. John's River in the Province of New Brunswick. (Figure 36).

The central portion consists of 6 spans in a continuous post tensioned box girder totalling 1256 feet, resulting in a performance need of 6 inches in longitudinal movement at each joint. Figure 37 shows one of the 6" modular systems that was installed in 1968.

Modular Systems on New Brenner Pass Autobahn.

The new Tyrolean Autobahn which runs from Innsbruck, Austria through the Brenner Pass utilizes a good many modular sealing systems on its long span bridges incorporating some of the highest piers ever constructed as it traverses the rugged Austrian mountains.

Typical of this construction are the 2476 ft. long Europabrucke (Figure 38) with piers 608 ft. high and the 5700 ft. long Luegbrucke (Figure 39).

Figures 40 and 41 are typical of the modular and multi-modular systems in service on the Brenner Pass Autobahn.

Figure 36. Florenceville Bridge over St. John's River in New Brunswick. Six spans, continuous box girder, 1256 ft. long.

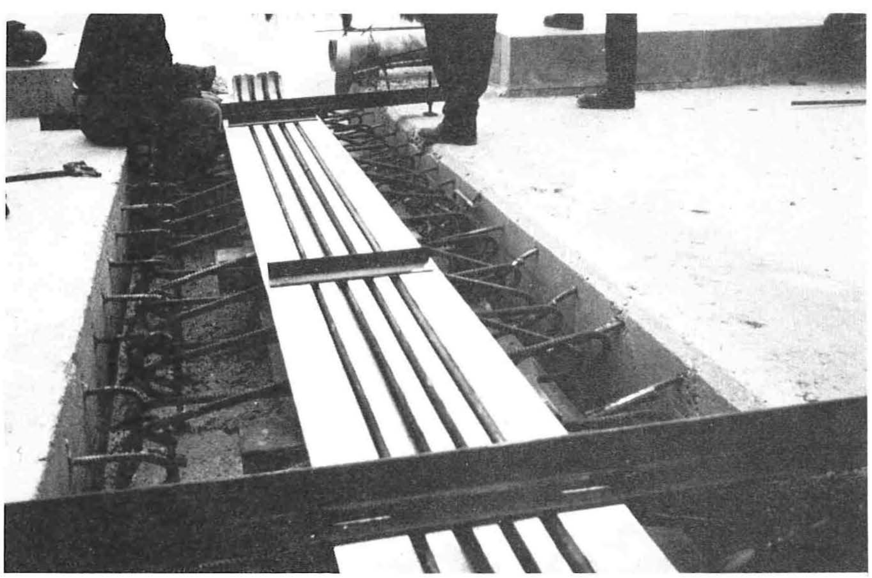


Figure 37. Installation of a 4-tube modular sealing system on Florenceville Bridge showing positioning member for perfect surface alignment.

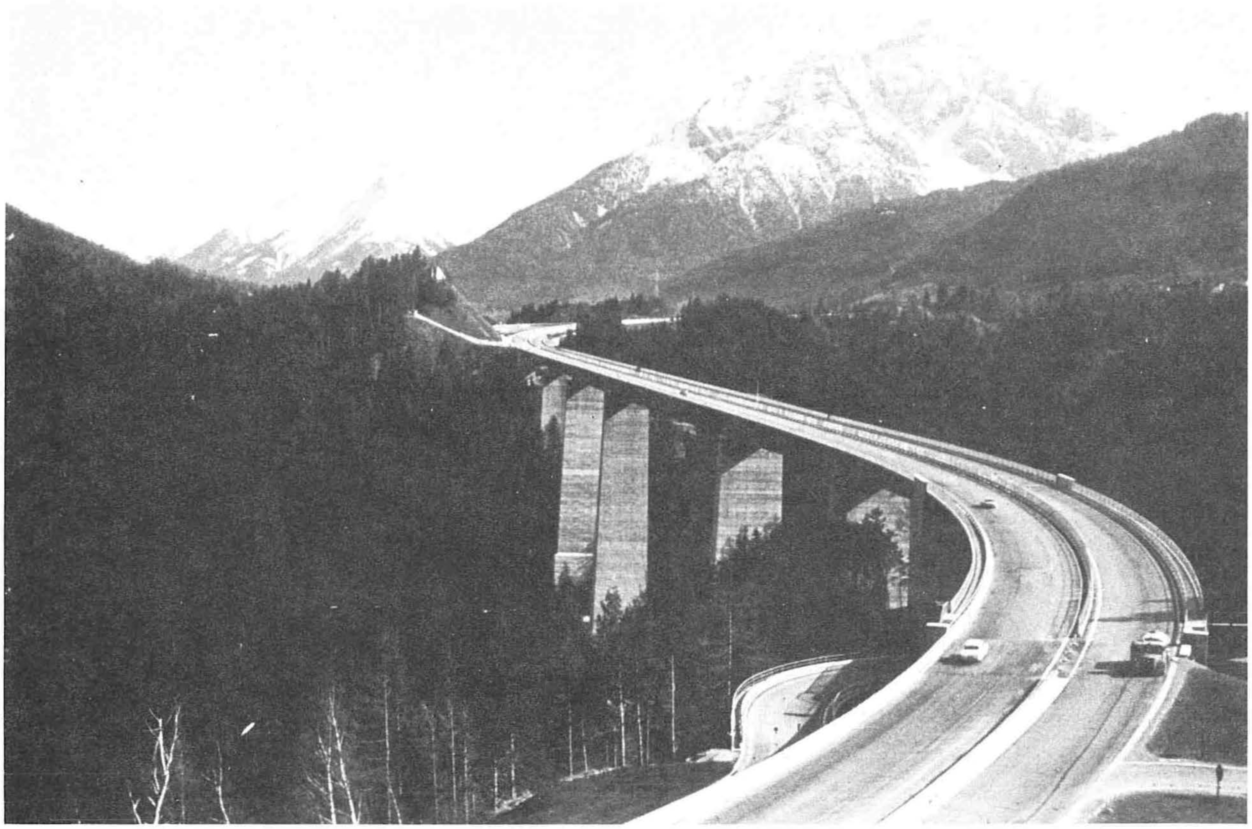


Figure 38. Europabrücke on Brenner Pass Autobahn is 2476 ft. long.

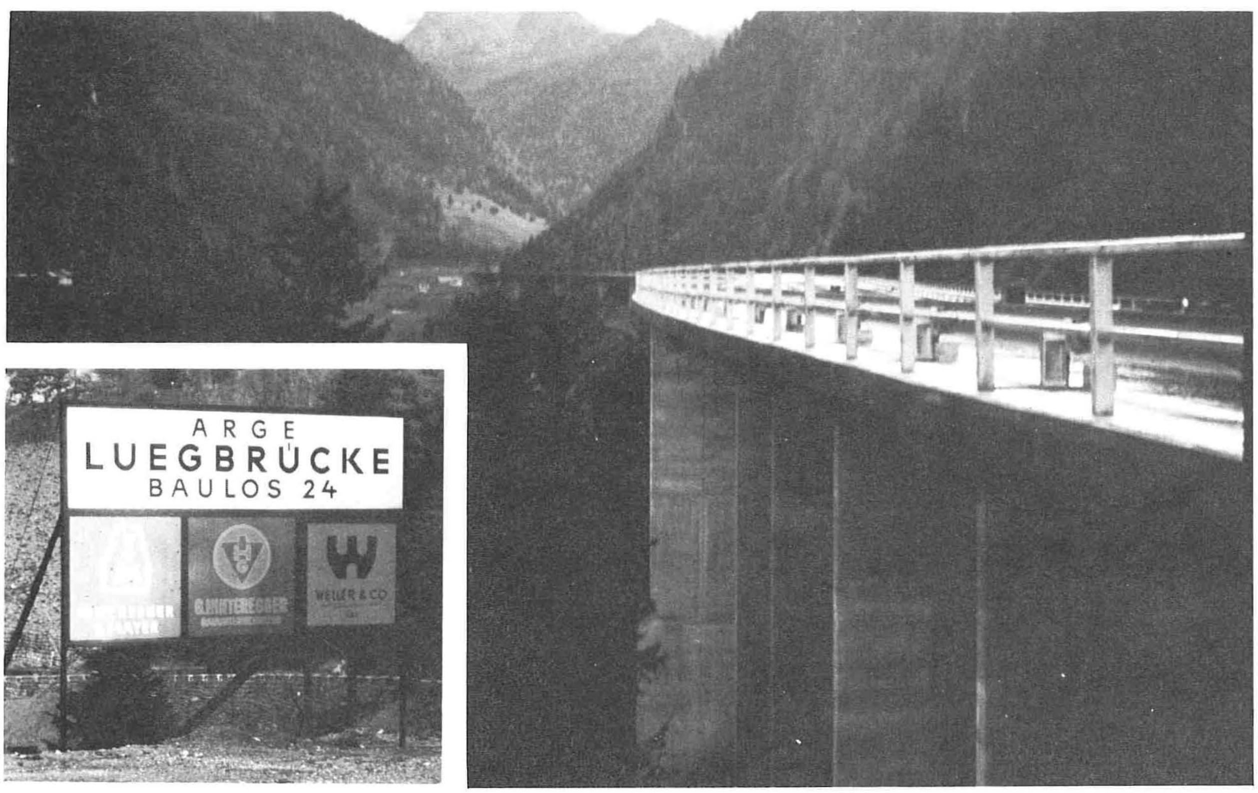


Figure 39. Luegbrücke on Brenner Pass Autobahn utilizes 5700 ft. long hybrid concrete box and steel girder design.

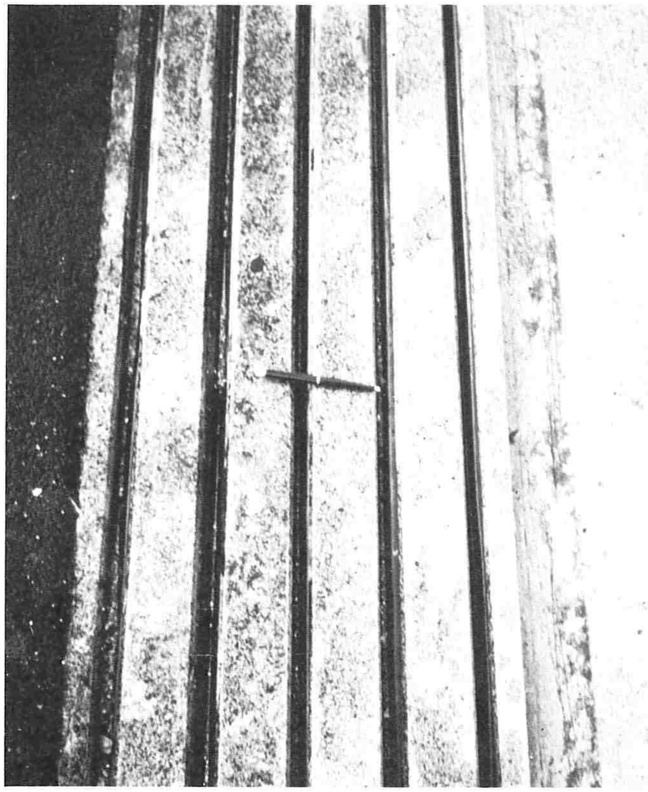


Figure 40. 5-tube modular system on Brenner Pass Autobahn incorporates 10-inch movement capability

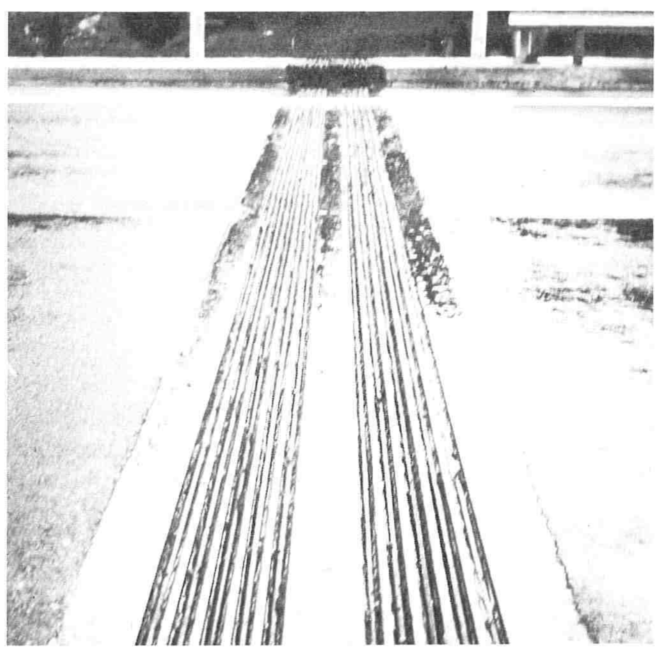


Figure 41. 10-tube multi-modular sealing system on Brenner Pass Autobahn for 15 inches of movement

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1 Wah, T., and Kirsey, R.; Thermal Characteristics of Highway Bridges; Southwestern Research Institute-1968.

2 Szilard, Rudolph; Corrosion & Corrosion Protection of Tendons in Prestressed Concrete Bridges; Journal of American Concrete Institute, January 1969.

Watson, Stewart C.

ABSTRACT

Single module, modular and multi-modular sealing systems appear to offer long term, maintenance free, solutions to newly developing problems at the joints being brought about by new design sophistication on our modern bridges and structures.

A redefinition of the need to extend the maintenance free life of our structures is graphicly illustrated by typical examples on a number of world famous bridges.

The historical reliability of the modular concept, the need for armored joints and their damping effect together with improved imbedment practices are discussed.

Upward and downward vertical forces, rotation, deflection and horizontal thrust movements, their effect on seal shapes and some solutions are advanced.

The typical bridge joint environment clearly dictates the need for heavy duty seal configurations. Web, top and side minimums, depth to width ratios, pressure generation requirements and specification standards are presented and analyzed.

Some existing methods of reliable deck temperature determinations, conduct of adjustment of a sealing system for temperature-width, placement techniques and construction practice for modular systems are given.

Improved bearing devices incorporating fluorocarbons, new snow-ice environmental problems, creep-shrink calculations, the use of scale models in solving skew problems, aerodynamic considerations and testing of modular and multi-modular systems are illustrated.

Some recent British, Canadian and Austrian Brenner Pass Autobahn modular solutions are evaluated and illustrated.